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# *Everyday Problems in Biology*

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# EVERYDAY PROBLEMS IN BIOLOGY



# EVERYDAY PROBLEMS IN BIOLOGY

BY

CHARLES J. PIEPER

WILBUR L. BEAUCHAMP

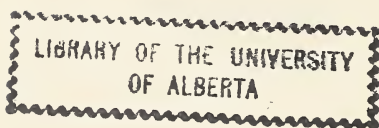
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ORLIN D. FRANK



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## DEDICATION

To the students whose interest and enthusiasm in science have made the preparation of this course of study such a pleasant and worthwhile enterprise, and to the students who, through a study of this book, will become better citizens of their communities.

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## PREFACE AND FOREWORD TO TEACHERS

The learning activities and subject-matter which comprise the course of study presented in this book are the outgrowth of eight years of experimentation on the selection and organization of biology for ninth- and tenth-grade pupils. The original units and the content within the units have been modified, revised, and recast several times in the light of pupils' reactions and successes and in the light of the criticisms of many teachers of biological science.

### GUIDING PRINCIPLES UNDERLYING THE COURSE

The guiding principles underlying the construction of the course may be summarized in a few major postulates:

(1) Biology is more than information and knowledge concerning living things; it comprises also methods of scientific thinking about and scientific attitudes toward ourselves and our living environment.

(2) Life, or living, is primarily a series of functions and activities more or less common to all living things. These activities result in adjustments. The course in biology, then, should be a study of any or all living things, leading to an understanding of the important functions, activities, and adjustments of organisms.

(3) The course in biology shall consist of a series of problems involving learning activities, properly motivated and directed by the teacher and carried out by the pupil in such manner that the pupil is led to the understanding of significant biological ideas, to the acquisition of the elements of scientific methods of thinking, and to the attainment of desirable attitudes toward life in its varied manifestations and significances.

(4) The learning activities of pupils in biology shall include a wide variety of those kinds of mental and physical activities

which are recognized as elements of scientific methods of thought and which make use of various sources of data as a basis for the solution of worthwhile problems.

(5) Biology aims to improve human behaviors in and adjustments to the living and physical environment; it is essential, therefore, that the pupil study both himself and his environment to the end that his behaviors be conscious, meaningful, and fruitful.

### MAJOR OBJECTIVES OF THE COURSE

The postulates and the experimental conclusions upon which this course is formulated imply certain major objectives which the teacher should bear in mind and set up as conscious goals for pupil attainment:

(1) To become acquainted with many living things: their characteristics, habitats, and activities.

(2) To acquire that information and knowledge concerning living things and one's self which satisfy the curiosity of youth and which may be of greatest practical and cultural value in life situations.

(3) To understand those significant, elementary concepts of biological science which provide the means for the interpretation of everyday biological observations, thoughts, experiences, and conclusions.

(4) To acquire, through the solution of real problems, understanding of and practice in those study skills and elements of scientific thinking which are significant in the field of science, to the end that these skills and methods of thinking shall function in the solution of similar problems in the everyday life of the individual.

(5) To develop toward the biological aspects of the environment and toward one's self those desirable attitudes which come through a clear understanding of biological concepts and through proper methods of study. These attitudes include, among others:

(a) Belief in cause and effect relationships in life functions.

(b) Respect for life and predisposition to protect and conserve life.

(c) Respect for the work and advice of experts in the field of biological science, pure and applied.

(d) An appreciation of the significance of biological science in modern social and industrial life.

(e) A feeling of being a part of the great stream of life and a desire to contribute to the betterment of life in all of its forms.

(6) To acquire an abiding interest in living things, which manifests itself in a variety of voluntary activities extending beyond the course in biology, such as reading biological literature, growing and caring for plants and animals, taking excursions to field, stream, park, and woods, and collecting biological specimens.

(7) To gain a perspective of the nature and scope of biological science, thereby revealing possible avocational and vocational fields and exploring the pupil's interests, abilities, and aptitudes for the further study in this or related fields.

(8) To perform those desirable mental and practical adjustments to the environment which are made possible through the attainment of the previously stated objectives.

#### CRITERIA FOR SELECTION OF CONTENT

The functional objectives which have been set for this course make imperative certain criteria for the selection of the content and activities:

(1) The materials and activities must be closely related to the natural interests of the pupils.

(2) The content must lend itself to scientific problem solving, to the interpretation of cause and effect relationships, to the formulation and testing of hypotheses on the basis of available data, to the development of generalizations, and to the application of generalizations in the explanation of novel problem situations.

(3) The understandings, skills, methods of thinking, and

attitudes sought as goals must be of everyday significance and value to the individual and to society.

(4) The degree of difficulty of the activities required of pupils must be such that the pupils can, through careful, directed study, accomplish results and be motivated toward higher attainments by the satisfaction which comes with accomplishment through reasonable effort.

(5) The activities must be definite enough to allow the possibility of measuring the success of their completion.

The constant re-selection and revision of the materials and activities during the years of experimentation have led to the present course of study.

### PRINCIPLES OF ORGANIZATION

The principles of organization which have governed the authors in constructing the course of study are those which have come to be recognized as valid by leaders in the field of science education and which have proved their worth during the experimental stage of this course. The more important principles are here stated:

(1) The course in biology shall find its point of departure in ideas familiar to the pupil in his ordinary round of activities in school and out. This way, orientation in biological concepts and methods becomes easy.

(2) The important functions, activities, and adaptations of living things are to be emphasized; the structures of organisms are to be considered only in so far as they aid in the understanding of the functions and in the recognition and classification of living things.

(3) The course shall be a synthetic course in general biology; that is, the study materials shall be taken from both plant and animal life, simple to complex, and lead to the understanding of the big ideas of elementary biology and their social significance.

— (4) The course shall be organized as a series of unit problems and sub-problems, each problem leading pupils inductively to the understanding of an important biological generalization.

(5) The learning activities and the self-testing exercises within each problem shall be of such nature and variety that pupils are given experience with and practice in those types and phases of thinking that are characteristic of scientific methods of thought in biological science and in life.

(6) The content of the course shall be so organized that the pupil becomes the center of activity and the teacher serves as a motivator and guide.

(7) The facts and concepts of physical science necessary to the solution of the problems shall be introduced when and where they aid in the understanding of the biological idea.

(8) Historical and biographical content shall be introduced when and where it will aid in arousing interest, in giving perspective and meaning, and in solving the problem.

(9) Reading materials, experiments, home projects, observations, diagrams, graphs, maps, and tables shall be introduced as sources of data for the solution of problems and not as content to be memorized.

(10) The inter-relationships of concepts developed in different units shall be emphasized by abundant cross-references, exercises, and questions to the end that the pupil may broaden his understandings as he proceeds through the course and may thus come to see life as a whole.

(11) The units and the activities within the units shall be so chosen and organized that succeeding units and activities will call for the understanding of broader and broader concepts and for progressively difficult reflective thinking.

(12) Human biology and its civic and social implications shall be distributed throughout the course, but shall also be given special emphasis in that part of the course which considers man's work in changing his natural environment.

(13) Each unit shall be so organized that the pupil's previous attainment of the specific objectives of the unit is measured before he begins the study of the unit and that his learning is motivated, directed, and tested. The unit problem is the "learning unit" or "lesson."

(14) There shall be provided with each unit enough supplementary and enrichment problems, projects, and exercises to insure that each pupil may advance according to his previous preparation, his interests, and his abilities. These supplementary activities should give pupils more applications of the concepts met in the unit and should extend the meaning and significance of the unit thought.

The principles stated have been formulated during the years of experimentation on the course of study and are the outgrowth of experience and of criticisms of hundreds of general-science and biology teachers.

The unit problems and sub-problems chosen for the book call for the understanding of those big ideas of biology and those biological facts which have been selected as most significant by analysis of textbooks of biology, courses of study, and books written by biologists for popular reading. Only those concepts which pupils at this level can comprehend are included in the course.

### SPECIAL FEATURES OF THE COURSE

Especial attention is called to the following features of the course:

(1) The method of orientation, which explains the strange in terms of the familiar.

(2) The unit-problem organization which follows essentially the same plan as the authors' *Everyday Problems in Science*.

(3) The preliminary exercises for each unit, which provide a means of inventory of pupils' experiences and concepts pertinent to the unit to be studied, and also serve as a means of motivating the study of the unit.

(4) The "Story" of each unit, which introduces the pupil to the new unit and at the same time raises the problems to be investigated as the work on the unit proceeds.

(5) The problem form of the pupils' study activities and the inductive development of the concepts through the use of textual and experimental materials as sources of data.

(6) The great variety of learning activities included, so chosen and distributed as to give the pupil acquaintance with and practice in those aspects of scientific thinking which the scientist employs in real problem-solving.

(7) The "Study Suggestions" which afford definite study helps and lead the pupil to be conscious of the elements of and procedures in scientific thinking.

(8) The provision for individual differences by the inclusion of many "Suggested Activities" in the text and of the additional exercises at the end of each unit.

(9) The glossary and pronunciations of new terms.

(10) The *Teacher's Guidebook*, published as a separate volume, contains detailed instructions and suggestions to the teacher for the successful conduct of the activities which comprise this course.

(11) *A Study-Book in Biology* (262 pages) provides an enriched activities program in the form of a pupil's work-book. This work-book is especially unique in that a considerable number of the exercises are so constructed as to make clear and force the use of scientific methods of working and thinking. Also, each exercise is focused on a major understanding, concept, or principle.

(12) A series of standardized objective tests in forms A and B is available for use with the text. The tests are bound in pads, each pad containing 12 tests, one for each unit of the book. The tests were standardized on returns from about 1000 students.

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THE AUTHORS.

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Life exists in myriads of fascinating forms. What do you think this photograph shows—a tropical jungle? No, these are merely tiny plants and animals that you can find in a few drops of pond water. Here they are shown magnified thousands of times. Tiny as they are, they, like the larger living things, must have food, can reproduce their own kind, and carry on many of the fundamental activities of life that you and I do.  
(Pinney Science photo.)

# EVERYDAY PROBLEMS IN BIOLOGY

## UNIT I

### HOW DO LIVING THINGS OBTAIN FOOD?

#### PRELIMINARY EXERCISES

1. In your notebook write the names of the animals as given in the left column below. For each animal select from the column at the right the part which that animal uses for food-getting.

| ANIMAL      | PART OF BODY            |
|-------------|-------------------------|
| horse       | pincers                 |
| elephant    | proboscis               |
| hummingbird | trunk                   |
| eagle       | teeth (and paws)        |
| cat         | lips                    |
| crayfish    | bill                    |
| squirrel    | tongue                  |
| earthworm   | tongue, teeth, and paws |
| ant-eater   | beak and talons         |
| butterfly   | lips and teeth          |

2. From the following words choose the correct one for each lettered space in the paragraph below. Write them in a column, correctly lettered, at the left of your notebook page.

|             |           |        |       |      |
|-------------|-----------|--------|-------|------|
| traps       | wings     | tongue | leaps | legs |
| feign sleep | structure | noses  | tails | paws |

Animals have many ways of catching other animals which they wish to use for food. The spider spins a web and ....(a).... its food. The leopard sometimes hides on a rocky elevation and ....(b).... upon the unwary animal which passes. Foxes have been known to ....(c).... to deceive their prey. Bears catch fish by thrusting their ....(d).... into the water. A frog is very skillful in catching flies with his ....(e)..... In the pursuit of food, fish use their ....(f)....,

birds use their ....(g)...., dogs use their ....(h)...., and moles use their ....(i).... Animals use different methods of obtaining food because of their differences in ....(j)....

**3.** Copy the letters in a column. After each letter write the correct word or words needed to complete the meaning.

The raw materials from which plants manufacture food are ....(a)...., ....(b)...., and ....(c).... These raw materials enter the plant through the ....(d).... and the ....(e).... The process by which these raw materials are changed to foods is called ....(f).... Most of the food is manufactured in the ....(g).... The machinery used to manufacture food is the ....(h)...., and the energy which operates the machinery comes from the ....(i).... The chief class of foods manufactured by this process are the ....(j)....

**4.** Below is a list of some of the parts or structures of which animals are built. Some of the parts are used for food-getting, some are used in food-getting and for other purposes, and some have no relation to food-getting. Copy the words in a column at the left of your notebook. Write "1" after those parts especially built for food-getting; "2" after those parts used in food-getting but not especially constructed for this purpose; and "3" after those parts which have no relation to food-getting.

|           |          |      |      |      |        |      |
|-----------|----------|------|------|------|--------|------|
| teeth     | bill     | eyes | feet | fins | lips   | paws |
| mandibles | feathers | nose | tail | ears | tongue | fur  |

**5.** Below you will find an incomplete statement followed by other statements. Some of these statements correctly complete the major statement, and some do not. Write the letters (a) to (e) in a column. Put a + sign after the letters of the statements which are correct and a — sign after those which are incorrect.

Food-getting is one of the most important activities in life because—

- (a) Living things must eat in order to carry on their activities.
- (b) Living things live in order to eat.
- (c) Getting food requires a large proportion of the time of living things.
- (d) Living things can never get too much to eat.
- (e) Living things cannot get food without some effort.



FIG. 1. Life is a constant search and struggle for food.

### THE STORY OF UNIT I

If you will keep a record of your activities for several days, you will find that, no matter how many different things you may do, there is one activity which you carry on every day. Shortly after you get up in the morning, you eat. You may then go to school, play games, or do odd jobs at home. In a few hours you are hungry and eat again. You probably also find it necessary to eat once or twice more before you go to bed. You know that, day in and day out so long as you live, you must spend a part of each day getting food and taking it into your body. In this respect you are like all other living things—like every one of the thousands of kinds of plants and animals that make up this living world of ours. Whether it be a tiny plant or animal so small as to be visible only under a high-power microscope (Figure 2), or a giant elephant or whale, every living thing must spend part of its time finding food and taking it into its body. Every day the great hungry mouth of the world must be fed.

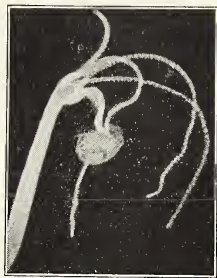


FIG. 2. Here, photographed through a microscope, is a tiny water animal, the hydra, capturing its food. With its wavy, stinging *tentacles* it has paralyzed a water flea. (Geo. T. Hillman photo.)

The best way to understand the part which food-getting plays in the lives of most animals is to visit the woods, fields, or vacant lots and watch whatever animals you can find. Keep a sharp look-out for bugs, bees, caterpillars, worms,

birds, and squirrels. Of course you will include in your observations such common farm and home animals as the horse, cow, dog, and cat. Watch them for as long a time as you can. What do they do? Are their activities aimless, or



FIG. 3. Living things get food in many different ways.

are they directed toward some goal? The more you observe, the more you will come to realize that living things spend most of their time eating or looking for something to eat.

As you observe animals in their almost ceaseless search for food, you will be impressed by another fact: Animals have countless different methods of finding, capturing, and taking food into their bodies. Eagles, kingfishers, bears, and others



FIG. 4. This eagle has captured a rabbit for its food. (Field Museum of Natural History photo.)

all like to eat fish, but each has its own method of capturing them. The kingfisher perches on a limb overhanging the water. When it sees a fish, it dives in, seizes it with its large, powerful bill, and flies away to swallow the fish or feed it to its young. The otter, on the other hand, is a swift swimmer and can twist and turn with amazing quickness. Therefore, it can pursue and capture fish. Can you tell

how the eagle and the kingfisher differ in their methods? The horse and the elephant both eat grass, but each has a different method of getting it into his body. The sheep and goat can find forage in rough, hilly, and even mountainous regions

where grass is sparse, but a cow could not thrive under such difficult conditions.

The examples given above raise several interesting questions: What other methods do animals use to get food? Why do they have these different methods? What parts of their bodies aid them in getting food?

In our observation and study of the ways in which animals get their food we must not forget to observe and study man. Primitive man probably spent most of his time searching for food. His life was very similar to that of other animals. The problem of food-getting is just as important today as it was in the time of primitive man. Today, however, only a certain per cent of our population (about 80 per cent) is actually engaged in producing food and distributing it. But those of us who are not actually engaged in food production must earn money with which to buy food. We can therefore say that food-getting is an activity of life which concerns everyone of us.

Although man, like the other animals, is engaged in the struggle for food, the problems which he faces are essentially different from those of the other animals. Alone in the forest or on the plain, without weapons, man would probably be unable to secure food as readily as does the tiger or lion. But for thousands of years man has been studying problems of food-getting, and as a result he has been able to perfect his methods far beyond those of the other animals. Why has man been able to perfect methods of food-getting to a higher

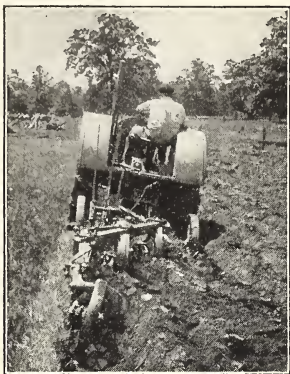


FIG. 5. Man has constantly improved his methods of food-getting. (International Harvester Company photo.)

degree than the other animals? What methods does he use which other animals do not? Can you answer these questions?

If you observe plants to discover how they find and take their food, you will probably not be successful in your search.

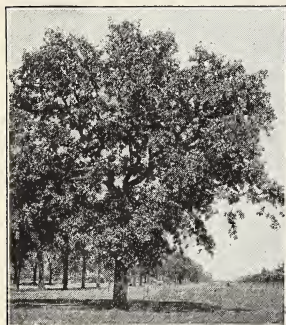


FIG. 6. Like man and animals, this great oak tree must have food or it will die.

Most of the animals which we know are equipped with legs, wings, or fins so that they can move from place to place in search of food. Our common plants, on the other hand, cannot move about. They must make their food from the materials which they obtain in their immediate surroundings. Their food-getting problem is thus essentially different from that of our common animals. This raises several questions, such as: What materials do plants use for food? Do they use for

food the same materials that animals use? How do they get materials into their bodies?

How food-getting is carried on by plants, animals, and man is the problem of this unit. Because animals and plants differ so markedly in their methods of obtaining food, you will consider these two groups of living things separately.

### PROBLEM 1: HOW DO ANIMALS OBTAIN THEIR FOOD?

**What different methods do animals use to get food?**

**STUDY SUGGESTION.** Naturalists have studied the habits of living things for many years and have recorded their observations so that others might learn. Some of these observations concerning the different ways by which animals obtain food are stated in the following paragraphs. The purpose of these paragraphs is to show that great differences exist; it is not necessary that you try to remember how each of these animals obtains its food.

*Observation 1.* One morning while taking a walk, I decided to observe the different methods used by birds in catching insects. I heard a rat-tat-tat on a near-by tree and saw a woodpecker climbing around, every few inches sounding the tree with his bill. Presently he stopped and commenced to chisel a hole. After a short time I saw by his actions that he had found for his morning breakfast an insect, or the larva of some insect (*larva* is the name given to one of the stages of growth through which insects pass before they become adults). Sitting on the branch of another tree was a small gray bird which I knew to be a flycatcher. Presently, it dived from its perch, opened its mouth, and flew back to its perch again. I had witnessed the capture of another insect. A little further on, I encountered a flicker in the pursuit of ants. It would wallow its tongue over the ants, withdraw its tongue into its mouth, and when the tongue was again seen, the ants were gone. A robin was



FIG. 7.



FIG. 8. The flycatcher captures his food on the "wing."

hopping along the ground, and presently it sighted an insect on a blade of grass. A flash of its head, and the insect was grasped firmly within its beak. Each bird had its own method of capturing insects for food.

*Observation 2.* I had often heard that cattlemen objected to the pasturing of sheep upon the grazing lands used for cattle. Various reasons were advanced for this objection, but the one reason to which all agreed was that sheep were likely to kill the grass. I wondered why this should be true. On comparing land over which sheep had grazed with that on which cattle had pastured, I discovered that, for some reason or other, the sheep

cut the grass much closer to the ground than did the cattle. They seemed to be able to get down almost to the very roots of the grass.

*Observation 3.* I was sitting by a window one day when I saw a cat slink through the bushes to a high board fence across the back of the lot.



FIG. 9. Cats are skillful food-hunters.

From her stealthy method of approaching the fence I was reasonably sure that she was stalking some small animal. Near the middle of the fence was a tree, and on the lower branches of this tree were several sparrows. I concluded that these sparrows were the object of her hunt. A minute

or two later the cat reappeared on a horizontal board which was nailed along the fence about a foot from the top. She crawled slowly along this board and remained concealed from the sparrows until she was directly beneath them. Then with lightning speed she leaped upward, with her paw knocked a sparrow from the limb, and landed on the ground with the bird in her mouth. She moved so quickly that it was almost impossible to see exactly how she did it.

*Observation 4.* Near where I live is a pond, the home of many small animals. One day while I was sitting quietly close to the bank of the pond, I observed a frog thrust its head above the water, and after a short survey of the surroundings climb on to a log. He sat there motionless, apparently resting. Soon a fly ventured near him. There was a flash of red from the frog's mouth, and the fly disappeared. I watched a while longer, and the same thing happened. The frog was sitting on the log catching flies for his food.

*Observation 5.* One day I observed a small hole in the ground. While I was wondering what animal made it, I de-

tected a slight movement near the top, and suddenly the hole was closed by the head of some animal. (I learned later that the animal was the larva of a tiger beetle.) Since the hole was bigger than the body, it was evident that the animal must be supporting itself by arching its supple body against the sides (Figure 10). While I was waiting to see what the animal would do next, I observed a small insect approaching. I saw that if the insect continued in the same course, it would pass right over the head of the larva. And that is what happened, or rather, almost happened, for just as the insect reached the hole, it was seized by the strong jaws of the larva. The larva then let go its hold and dropped, carrying the insect with it. Once at the bottom of the hole,



FIG. 10. A tiger-beetle larva sets its trap.



FIG. 11. A dragon fly has blundered into the sticky web. The spider now has its food supply at hand for several days. (Photo © Lynwood Chace.)

where its prey had little chance of escape, I have no doubt that the larva very quickly made a meal of the unsuspecting insect.

*Observation 6.* As I was sitting on the front porch one day, I saw that a spider had made use of some vines which had climbed the posts, as a means for anchoring a web which she had spun. The spider had taken her stand in the centre of the web and was apparently resting from her labor. Presently a fly came along and

was caught by the sticky threads in the outer part of the web. Immediately the spider ran to the fly and covered it with more sticky threads until it was entirely bound. Then she pricked her victim with her poison fangs and withdrew to the centre of the web. When the fly had ceased its struggles, the spider dragged it to the centre of the web and leisurely proceeded to suck the juices from its body.

**SUGGESTED ACTIVITY.** The observations given above illustrate but a few of the many different methods which animals use to get food. You will find it interesting to make a few observations of your own. Observe carefully a cow, horse, pig, cat, dog,

bird, chicken, goldfish, squirrel, or any other animal which you can find. Prepare as detailed a description as you can of exactly how the animal finds food and takes it into its mouth. Wild animals, especially those which eat other animals (these are called *carnivorous* animals), get their food



FIG. 12. The ant-eater has no jaws, but when he finds an ant-hill, his pencil-like, sticky tongue slips in and out with great rapidity carrying its loads of food.

in many strange ways. You cannot observe all these yourself, but you can find many interesting stories about lions, pythons, ant-eaters, whales, turtles, leeches, starfish, cuttlefish, wasps, beetles, and many others.

### **Why do animals differ in their methods of getting food?**

**STUDY SUGGESTION.** In solving a problem like this it is well to study in some detail several animals and then try to arrive at general statements concerning why animals differ in their methods of getting food. It is not your purpose to be able to tell in detail how each animal gets its food, but rather to find an answer to the problem, "Why do animals differ in their methods of getting food?"

A study of how animals get their food presents us with a bewildering number of methods. Each animal apparently has its own method. Different animals eating the same kind

of food differ in their method of obtaining it. Why is this true? To answer this question, we shall consider some of the examples which have just been discussed.

A comparison of the animals using insects for food provides data to answer our problem. The flycatcher has a wide mouth with stiff bristles on each side of it. When it pursues an insect, it opens its mouth and the



bristles stand out on each side (Figure 8). These bristles act like a funnel to catch the insect and direct it into the mouth of the bird. The woodpecker has a long, sharp bill which he uses to sound the trunk of a tree to discover

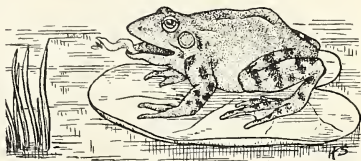


FIG. 13. How a frog captures flies.

decayed or hollow spots where insects are likely to be present. The beak is so constructed that it is possible by continuous pecking to drill a hole in the tree. The woodpecker then sticks his long, flexible tongue into the hole. This tongue is sticky and spear-like; so the insects with which it comes into contact simply stick to it and are drawn into the woodpecker's mouth. The frog, on the other hand, uses its tongue in an entirely different manner from the birds (Figure 13). Its tongue is attached at the front of the mouth instead of at the back like most other animals. When the fly is close enough, the frog simply flips out its tongue, encircles the fly, and brings it back into its mouth. The spider is able to spin a sticky thread with which it can construct its web; it is also able to paralyze its victim with a poison from its fangs.

Let us see why the sheep crops the grass so closely to the ground. In grazing, the sheep places its lower jaw on the ground behind the grass which it wishes to eat. It then

pushes its tongue around in front of the grass and holds it against the teeth. Then by an upward thrust of the lower jaw, the teeth cut the grass. The cow eats grass in the same manner, but since the lower jaw of a cow is much thicker than that of the sheep, the teeth are not so near the ground; hence the grass is not cut so short.

**SUGGESTED ACTIVITY.** Observe birds capturing insects, and report to the class what you saw. Try to explain just why they use different methods.

**SUGGESTED ACTIVITY.** Observe a horse or a rabbit eating grass. Compare the methods they use with those of the cow. Explain why they differ in their methods.

Each of the animals described is different from the other animals in its *structure*, that is, in its kinds of body parts and in the forms of these body parts. A dog laps water, a horse sucks the water in, and a chicken fills its beak with water, then raises its head and lets the water run down its throat. If you will examine the tongue of a horse and that of a dog, you will find that the dog's tongue is wide, flexible, and thin so that it can make it into the form of a cup. The tongue of a horse is thick and could not possibly be used in this manner. The horse can drink water even with its head lower than its body because there are circular muscles in its *esophagus* (the tube which leads from the mouth to the stomach) which contract and force the water up. The chicken, on the other hand, has no such muscles and hence must have its head above its body so that the water may flow downhill. The method which an animal uses in getting food is thus dependent upon the structure of the animal.

The discussion to this point has been concerned with the more complex animals, that is, animals which are made up of many parts. We must not, however, neglect some of the simplest animals, because they, too, have the problem of getting food. Let us first examine one of the simplest animals, the *amœba*. This animal is about one-fiftieth inch in diameter and can be observed only by use of a powerful microscope.

**Experiment 1.** How does the amœba get its food? To get an amœba, obtain some leaves from the bottom of a stagnant pool, place them in a jar of water, and allow it to stand for several days out of the direct sunlight. A jelly-like scum will form on the water. Remove a drop of this scum with a medicine dropper and place it on a glass slide. Place a cover glass over the drop of water and examine it under a powerful microscope. (Your teacher will show you how to use a microscope.) By careful observation you will find an animal such as is shown in Figure 14. Notice how the animal moves. Notice the behavior of the animal when it comes in contact with a piece of food. How does it take food into its body?

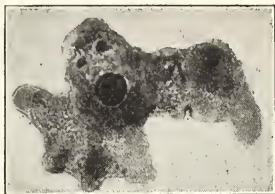


FIG. 14. How an amœba appears under the high power of a microscope.

The amœba has no mouth, eyes, teeth, ears, nose, or any of the body parts which we see in large animals. It is as simple as an animal can be. It has no way of locating food except by coming in contact with it. If the amœba comes in contact

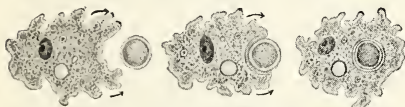


FIG. 15. How an amœba takes in its food.

with a solid piece of material which it cannot use for food, it rolls over or past it; if it is good for food, the amœba surrounds it with its body (Figure 15). For some reason, which we do not fully understand, it acts differently in the presence of materials which are food and those which are not.

Another very simple animal, and one which is easy to obtain, is the paramecium.

**Experiment 2.** How does the paramecium get its food? (a) To obtain a paramecium, make a hay infusion by soaking dry hay in a small jar of water for a week or more. By means of a medicine dropper take up a small drop of water near the surface of the water and the side of the jar. Transfer the drop of water to a slide and

cover with a cover glass. Mount under the low power of a compound microscope, and look for rapidly swimming organisms like that shown in Figure 16. Note the oral groove or mouth and the minute hairs, or *cilia*, found on the outer surface of the body. (Study Figure 16 for names and location of parts.)

(b) Obtain another drop of water containing paramecia and add a little powdered carmine, stirring it through the drop. Cover the

drop with a cover glass and examine under the microscope. If possible, find a paramecium which is comparatively quiet and watch it feed on the carmine. You will note the particles of carmine scattered through the body. How do they get inside the paramecium?

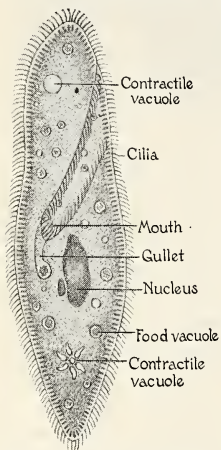


FIG. 16. In Unit II you will learn the functions of the vacuoles.

The paramecium is a little better equipped for food-getting than the amœba. It can move much faster than the amœba; it has a definite place for entrance of the food, and it has cilia to sweep particles of food into this opening.

The amœba and paramecium are examples of the simplest forms of animal life. The body of the amœba is less complex than that of the paramecium; it has no mouth or cilia. The two animals have a different structure; that is, the materials of which they are made are put together differently, giving different forms to their bodies. As we proceed up the scale of animal life, that is, from the simpler animals to the more complex animals, we find an ever increasing complexity of structure and a greater variety of body parts which are used by the animal in getting food. The hydra, which you saw in Figure 2, has long *tentacles* with which to grasp the food that comes to it and force it into the mouth at the base of the tentacles. These tiny water animals also have, scattered over their bodies, dart-like organs

which by a stab and a discharge of poison paralyze and even kill the minute creatures on which they feed.

Let us examine an animal still more complex in structure, the earthworm. It has neither eyes nor ears to tell it of the presence of food; so it must depend upon coming into contact with food. By means of its stiff upper lip it can attach itself to a piece of soil or to a leaf (Fig. 17). The *pharynx*, located directly behind the mouth, has muscular walls which can expand and contract. This makes it possible to enlarge or decrease the size of the pharynx. As the pharynx enlarges, the air pressure becomes less inside the animal than it is outside. The piece of soil or leaf to which the animal has attached itself is thus forced into the mouth by the outer air pressure. In this manner it burrows its way through the soil. As the materials taken into the body pass through the worm, the digestible parts are used by the worm as food. The earthworm by reason of its structure is *adapted*, that is, fitted, to obtaining food from the soil in which it lives.

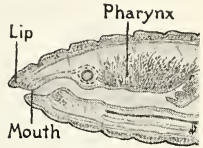


FIG. 17.

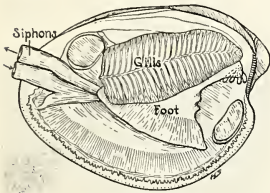


FIG. 18. The clam can only drag itself slowly along with its foot. It therefore cannot be said to search for food.

Most of the animals which we know have parts used especially for food-getting. The clam has a double-tubed siphon which is extended into the water (Figure 18). Cilia are located in one tube, and these by their constant motion cause a current of water to pass into the animal. Small animals and plants are carried inward by the current and swallowed. Since the food is so small, the clam needs no teeth or other organs to seize the food. The crayfish and the lobster have large *pincers* which enable them to seize food; they have *mandibles* which move sidewise and crush the bits of food into smaller pieces.

Birds are equipped with bills of various kinds, and some have powerful hook-like beaks and sharp *talons*. Birds which feed on insects have one kind of bill; those which feed on fish

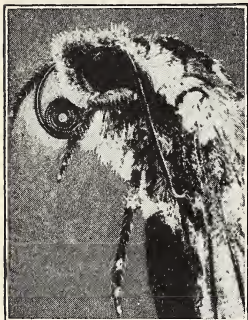


FIG. 19. Moths also have sucking probosces like that of the butterfly. This picture shows the proboscis of a moth.

have another kind, and those which feed on seeds have still a different kind. The butterfly has a long tube, the *proboscis*, which it keeps curled up under its head until feeding time. When it alights on a flower, it uncoils the proboscis, extends it down into the nectar cup at the base of the flower, and "sucks" the sweet nectar into its body (Figure 19).

Most of the common animals have teeth which are used as organs of *prehension*, that is, for grasping and holding the food. As shown in Figure 20, the teeth of a snake

curve inward. They are not used for grinding or cutting the food, but for seizing the food and keeping it from escaping. Snakes usually swallow animals whole. They have no hands or other structures to help them hold the food and convey it to the mouth. Once the snake gets an animal in its mouth, the curved teeth will prevent the animal from getting away. Also, the jaws of the snake work independently of each other and are joined by very flexible muscles. This enables the snake to force food into its mouth by moving first one jaw and then the other.

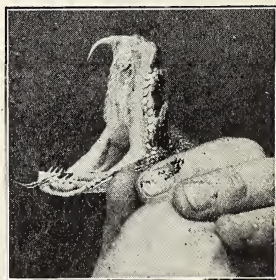


FIG. 20. Note the two poison fangs at the end of the upper jaw and the small, sharp, inward slanting teeth for grasping food. (Field Museum photo.)

The cat family, such as the house cat, lion, and tiger, is well equipped with structures for food-getting. Their bodies are well formed and remarkably strong for their size. They have pads or cushions on their paws, which enable them to move silently. Their sharp claws are folded back under these pads, but they flash forth when the animal leaps for its prey (Figure 21). Their senses of sight and smell are extremely well developed, and are valuable aids in the search for food.



FIG. 21. An African lion ready to leap upon his prey. (Field Museum photo.)

The tongue of the lion is covered with small, horny points which enable the animal to scrape the flesh of its prey from the bones. It is said that one slap of the lion's tongue on a man's hand will strip it of flesh. The lion also has long, pointed teeth which enable it to seize and tear the flesh of the animals it eats. The teeth in the rear are cutting teeth, the upper teeth going a little past the lower ones so that they cut the flesh like scissors. For pursuing his game, the lion is provided with legs which can carry him at the speed of a horse.

The abilities to smell, to see, and to hear are very important aids in locating food. Not all animals, as we have seen, possess these abilities. The dog has a markedly well-developed sense of smell. All of you have probably seen a dog following the trail of a rabbit. The cat, on the other hand, makes use of her sharp eyes to detect the slightest movements. You will never see a cat following the trail of a mouse with her nose. You have probably noticed that a cat does most of her hunting at night. She is able to see at night because of the way in which her eyes are constructed. The pupil of the eye, through which the light enters, can be

changed from a narrow slit to a wide ellipse. This enables the cat to open the pupil widely at night so as to obtain the greatest light possible. The ability to hear is also of great advantage to hunting animals, although it is perhaps not so important to them as the ability to see and to smell.



FIG. 22. Dogs have a keen sense of smell but rather poor eyesight. (*Field and Stream* © photo.)

Closely associated with the ability to see, to smell, and to hear are the other senses, touch and taste. These are most helpful in determining what is good to eat and what is not. The grasshopper walks along the stem of a plant and touches everything with its *antennæ* (Figure 23). When it touches a green leaf, it stops and eats it. The *antennæ* are thus used to locate materials which may be used for food. The snake carefully examines its prey with its long, forked tongue before it will eat. Experiments with animals have also shown that the sense of taste guides them in their selection of food.

In addition to the many body parts which are of direct use in food-getting, animals also utilize other parts of the body for this purpose. The organs of locomotion, which enable animals to crawl, swim, hop, run, walk, and fly are important in that they permit the animal to pursue its prey or to change its location when the food within its immediate vicinity is exhausted. The pig uses its tough, gristle-like snout to plow into the soil for fleshy roots and nuts. The mole uses its slender nose and its feet to push its



FIG. 23. Young grasshoppers on clover stems.

way through the soil in search of the worms, roots, and seeds which are its diet. The python uses its tail to attach itself to the limb of a tree and hang suspended in the air waiting for an animal to pass beneath it. Animals thus possess an endless variety of body parts which are used in the activity of getting food.

Not only do the ways in which animals get their food depend upon their external structure, but they also depend upon the characteristics inherited from their parents. It is not necessary to teach a dog how to hunt food. A spider may be hatched from the egg and kept entirely apart from other spiders; it will, however, spin its web and use the same methods of hunting food as other spiders of its own kind. We shall learn in a later unit much more about inherited abilities and how they affect the life of an animal.



FIG. 24. A python hanging ready to launch itself upon its prey. (Field Museum photo.)

**Self-testing exercise 1.** On the basis of the descriptions of animals in the preceding paragraphs, plus your own knowledge of how living things get their food, make a list in which you name the body parts used in getting food, and describe the ability which each part gives to the animal. Arrange your work in the following form:

#### BODY PARTS USED FOR FOOD-GETTING

| BODY PART | ABILITY                      |
|-----------|------------------------------|
| Eyes      | Enable animal to see         |
| Bill      | Enables animal to grasp food |

**Self-testing exercise 2.** Below the table which you have constructed for Exercise 1 write a paragraph in answer to each of these questions: (1) What parts of the body aid animals in food-getting? (2) Why do animals differ in their methods of getting food?

**How does man get his food?** In man we find what seems to be an exception to the general principle that the method of



FIG. 25. Primitive man, like the animals, spent most of his time searching for food. He had only the swiftness of his feet and the strength of his body to help him. (Field Museum © photo.)

food-getting of an animal is dependent upon the structure of the animal. Man eats all kinds of food; he is *omnivorous*. If the food does not suit his taste when raw, or if it is too tough, he cooks it. He does not need strong muscles or sharp teeth to strip the flesh of animals from the bones. He has knives, cleavers, and other sharp instruments for this purpose. He is not dependent for food upon the living things found in his immediate surroundings. But he is dependent upon his structure for the complex methods of food-getting which he has developed. This can be shown by a study of his past.

Many thousands of years ago man had not reached his present state of civilization.

Through the discovery and examination of the remains of primitive man, scientists have been able to obtain a fairly accurate picture of life in the ages past. Primitive man had much the same problems as other animals (Figure 25). He was dependent for food upon his skill as a hunter. He used the structures which he possessed in exactly the same way as other animals. He stalked his game,

pursued it when he could run fast enough to catch it, and used his teeth and his hands to capture and kill his victim.

As time went on, man improved his methods of hunting by inventing weapons with which he could kill or capture his food. His ability to invent and use weapons was the result of a brain capable of much higher development than that of the other animals. It is this brain which has enabled him to become master of the rest of the living world. Through the use of it he has been able to develop a language by means of which he can make his thought known to others and receive their thought in return. Language has made it possible for the discoveries, ideas, and inventions of one generation to be passed on to the next generation. Man's complex methods of getting food are thus the result of thousands of years of experimentation in which many people have coöperated. Man is no exception to the general principle that the method

of food-getting is dependent upon structure. Man's methods can be traced to the possession of a brain which has been developed to a much higher level than that of any other animal.

The development of man's control of the food supply has required thousands of years. One of the great steps forward took place when man began to domesticate plants and animals and raise them for food. Ever since this early beginning, man has been studying the conditions necessary for the growth of plants and animals, and today we have a science of agriculture. As a result of these long years of study, man has selected certain plants for food; these he cultivates and harvests. Not



FIG. 26. This picture shows three all-important ways in which man's brain has helped him solve his food problems. He has learned to domesticate animals, cultivate plants, and make machinery.

only does he raise food for immediate use, but he also stores plant foods for use during the long winter months when growth stops; he preserves animal foods in cold-storage. The story of man's improvement of growing conditions and his methods of selecting and breeding the plants and animals which he uses will be told in Units VII and VIII.

Life in the open is a constant struggle for food. The necessity for food to maintain life and the constant warfare among animals to obtain food is a major problem in the life of every animal. Some animals because of their particular structures are essentially hunters; others because of their lack of equipment are the "hunted." But the hunters in turn may be hunted by others. The success of the animal in getting food and in keeping from becoming food for some other animal is an important factor which determines how long he shall live.

**Self-testing exercise 3.** Make a list of as many ways as you can in which man has improved his methods of producing and distributing foods.

**Self-testing exercise 4.** Read through your answers to the preceding exercises in this problem and then prepare a summary not more than one-half page in length which will fully answer the problem, "How do animals obtain their food?"

## PROBLEM 2: HOW DO PLANTS OBTAIN THEIR FOOD?

Food-getting presents a different problem to plants than it does to animals. When an animal is hungry, it uses whatever means of locomotion it has to go in search of food. A tree, on the other hand, cannot change its location. It has no legs, no wings, no fins to move it from place to place; neither does it have hands, pincers, or claws to help it get food into its body. Moreover, it has no mouth through which the food may enter. We know, however, that in some way or other it must get food, or it will die.

To discover the source of the food supply of green plants we must examine their surroundings (Figure 27). The roots

of land plants push their way downward and outward into the soil, and the stem and leaves grow upward into the air. Since the air and the soil are the only materials with which the plant comes in contact, they must be the source of the plant's food supply. The soil, as you know, consists of minerals which have been released by the wearing away of the rocks, decayed plant and animal materials, and water between the particles of soil. The air is a mixture of gases, chiefly nitrogen and oxygen with a small per cent of carbon dioxide and certain rare gases.

But when we make chemical tests of a leaf or other part of the plant, we find materials which are not present in the soil or in the air. For example, green plants contain *starch*, *sugar*, and *proteins*. Some contain *fats* or oil. But none of these materials is found in the soil or in the air. It is evident, therefore, that green plants must have some method of changing

into new materials the materials which they get from the soil, air, and water. In other words, the materials which the plant gets from the soil and the air are not foods; they are the raw materials from which the plant must manufacture its food.

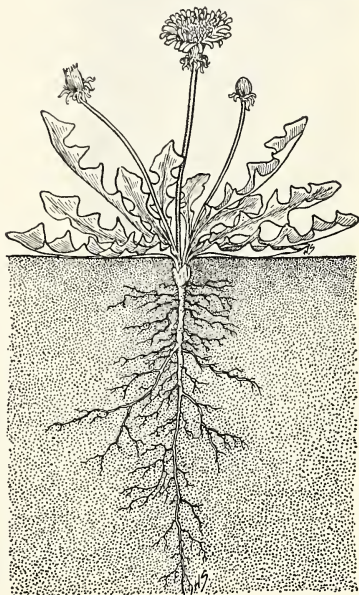


FIG. 27. From the soil around its roots and the air around its stems and leaves the plant must get its food.

**How does the green plant get its raw materials?** If you wish to understand how a factory is operated, you must visit it and observe the machinery and the different processes which are carried on. Now a green plant does not contain rooms

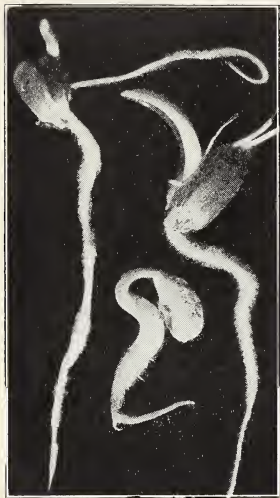


FIG. 28. The fuzzy appearance of the roots of these sprouting corn and bean seeds is caused by the thread-like root hairs.

and machinery, but it does have different parts, each of which has a special work to do in getting the raw materials into the plant and changing them into new products. The first step in this process is that of getting the raw materials. We shall now examine this process.

One source of raw materials is the soil. In order to understand how materials from the soil can enter the plant, it will first be necessary to examine the structure of plant roots.

**Experiment 3. What is the structure of plant roots?** (a) Plant wheat, beans, and peas in some wet sawdust or loose soil. Keep the container in a warm place where there is plenty of light, and from day to day add enough water to keep the sawdust or soil moist.

Examine the small "garden" from day to day, observing the growth of the seeds. When the plants are several inches high, take one of them out by carefully removing the soil or sawdust from around the roots. Examine the root system, make a drawing of it, and below the drawing describe its appearance.

(b) If a magnifying lens or low-power microscope is available, remove another plant from the container and immediately examine a small branch of the roots to see the fine thread-like projections, or *root hairs*, which extend outward from the root branch (Figure 28). Be sure to soak the soil or sawdust well before uprooting the

plants; otherwise the root hairs will be broken off. Wash the roots well and examine them carefully in a drop of water. You may find it necessary to examine several root branches before finding the root hairs, because most of them are broken off when the plant is removed from its growing place. Make drawings showing (1) how the root hairs are attached to the branches of the root system and (2) how the root hairs cling to fine particles of soil.

(c) Dig up some plants which are growing in a vacant lot or field. Be careful to secure as much as possible of their root system. Obtain a rough measure of their root system by measuring the length of each of the small rootlets. Why is such an extensive root system necessary?

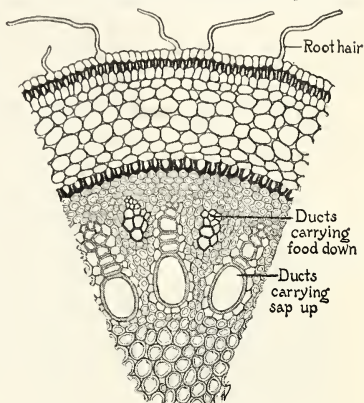


FIG. 29. Cross section of root, highly magnified, showing cells and root hairs.

In order to see the root hairs of a plant more distinctly, carry out the following experiment.

**Experiment 4. What is the nature of the root hairs?** Place some wet blotting paper in a saucer or Petri dish; then sprinkle a dozen mustard, radish, or wheat seeds on the paper. Cover the dish with a glass plate to prevent loss of moisture, and leave it in a warm place. After a few days examine the fine root hairs which branch out from the tiny roots, giving the roots the appearance of cotton. If a magnifying lens is at hand, you can place it directly over the glass plate and examine the root hairs without removing them from the dish.

When the roots are placed under the high power of a compound microscope, their structure can be plainly seen (Figure 29). Note that the root is composed of tiny box-like structures or *cells*. Under the microscope the cells appear to be flat, but

in reality they have three dimensions, length, breadth, and thickness. You will find, if you do not already know it, that all living things are composed of cells. Figure 29 shows that the root hairs are long tube-like parts of the cells of the roots. They are not divided from the root cells by walls, but are merely extensions of these cells. If you could examine the root hairs with a powerful microscope, you would find that they have a very thin cell wall around them. Inside this wall is a thin layer of living substance (the *plasma membrane*), within which is a thick liquid called *cell sap*. The root hair is the structure through which the plant obtains raw materials from the soil. The process by which these materials pass through the thin walls and membranes is called *osmosis*.

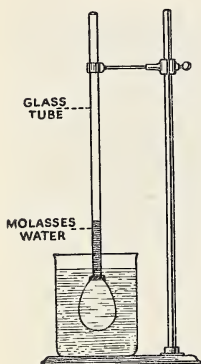


FIG. 30.

**Experiment 5.** What are the conditions necessary for osmosis to take place? (a)

Carefully break away the shell from a small area of the large end of a hen's egg without breaking the membrane which is just under the shell. (See Figure 30.) Then carefully punch a small hole through the small end of the egg, and shake all of the white and yolk of the egg from the shell. When this is done, fill the egg with molasses water made of one part molasses and one part water. Then place a glass tube over the small hole which you made, and seal it in position with sealing wax. Carefully lower the egg into a glass of water and let it stand as in Figure 30 for several days, observing what happens. (A pig bladder may be used satisfactorily as a substitute for the egg.)

(b) Repeat part (a) of the experiment, but use water both in the egg or pig bladder and in the glass. Does the water rise in the tube?

(c) Repeat part (a) of the experiment, using a mixture of starch and water in the egg and water in the glass. (Starch does not dissolve in water.) What results?

**Self-testing exercise 5.** In Experiment 5 three sets of conditions are obtained: (1) Water and sugar are separated from pure water by a membrane. (2) Pure water is separated from pure water by a membrane. (3) Water containing a substance that will not dissolve is separated from pure water by a membrane. What are your conclusions as to the conditions necessary for osmosis?

In the experiment the tube and the membrane of the egg represent the root hair of a plant. The molasses represents the cell sap, and the water in the glass represents the soil water which surrounds a root hair. The rise of the liquid in the glass tube shows you that the volume of the liquid inside the egg is increasing. The water from the outside *permeates*, that is, it slowly passes through the pores in the membrane. The water of the sugar solution in the egg also passes out through the membrane, but much more slowly than the water passes into the egg. The result is therefore an increase in the amount of material within the egg. As the volume inside increases, the liquid is forced up the tube. This same process goes on in plants. The soil water goes into the root hair. As the volume inside gets larger and larger, the liquid is forced upward through the root branches into the stem of the plant. Thus you see one method of bringing water from the soil into the plant factory.

You have seen that water enters the roots by the process of osmosis. Does this water contain other materials?

**Experiment 6.** Are there dissolved materials in the water which enters the plant? (a) Tie a cloth over the top of a lamp chimney and support it inverted over a tumbler (Figure 31). Pour in coarse sand to make a layer about two inches thick. Now add fine sand to a depth of two inches. Fill the remaining

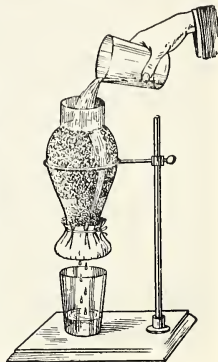


FIG. 31.

space with soil. Pour in distilled water at the upper opening of the chimney, and collect the water which runs through into the tumbler. The water in the tumbler will now be similar to the water in the ground.



FIG. 32. An onion leaf under a microscope shows plainly the epidermal cells and the stomata. It has been estimated that a sunflower leaf of medium size contains about 13 million stomata.

and stem. Does air enter the leaf? If so, how? If a thin strip of a leaf is examined under the microscope, its structure can be seen (Figure 32). Like the root, it is composed of cells. The outer layer of cells form what is called the *epidermis*. It is through the epidermis that the air must come if it enters the leaf.

**Experiment 7.** What is the nature of the epidermis? Remove a small bit of the "skin" from the under side of a lily leaf or the leaf of the house leek and place it under a microscope in a drop of water. The regular epidermal cells are more or less rectangular-shaped. Here and there you see pairs of crescent-shaped cells called *guard cells* (Figure 33). The openings between the guard cells are called *stomata*. (The singular of stomata is *stoma*.)

**How are the raw materials brought to the leaf?** Since in most green plants the raw materials are made into foods in

(b) Pour the water into an evaporating dish and heat it on a ring stand until the water disappears. Examine the bottom of the evaporating dish. What do you find? What is your answer to the question asked in this experiment?

(c) Now try this check experiment: Boil distilled water until it disappears. What do you find in your dish? Conclusion?

A second possible source of raw materials is the air. The parts of the plant which come in contact with the air are the leaves

the leaves, the water and minerals which enter the root hairs and the air which enters the leaf through the stomata must be brought together inside the cells of the leaf. Certainly plants must have some forces within them which bring the water and minerals from the roots up to the leaves. Some plants have very short stems; so the raw materials need to be lifted against gravity for only a short distance to reach the leaves. In the case of tall trees, however, the water and minerals need to be lifted great distances.

How water is lifted in plants is not thoroughly understood by scientists. They are sure that one force is *osmotic pressure*. This is the force, you know, which causes the water of the soil solution to go through the membranes of the root hairs into the cell sap. It thus increases the volume of the sap. As the volume increases, the liquid is forced upward through certain cells in the stem of the plant.

Another factor which assists in the passage of water through the plant is the capacity of the cell walls of plants for absorbing water. This capacity for absorption can be demonstrated by the following experiment.

**Experiment 8.** What effect is produced when dry seeds are soaked in water? Obtain a small flower pot. Fill the pot with dry seeds such as peas or beans. Cover the top of the pot with a brick, and wire this firmly in place. Place the flower pot in a pail of water. Examine the pot on the next day. What happened?

This absorption of water by organic materials is known as *imbibition*, and as the experiment shows, dry organic matter swells with considerable force.

It can also be shown experimentally that water is constantly escaping from the plant through the stomata and

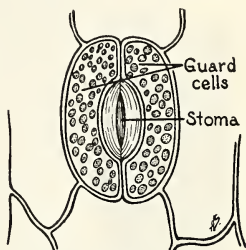


FIG. 33. The stomata are tiny openings in the leaf. You will learn more of the operation of these guard cells in Unit V.

evaporating into the air. This, of course, means that the cell walls lose part of their moisture. Through a combination of the forces of imbibition and osmosis, water is thus pulled from the adjacent cells to make up for this loss. This process continues from cell to cell back to the root hairs. Experiments have indicated that these two forces may easily be great enough to lift water from the soil to the tops of the highest trees.

The rise of the liquid through the stems of plants can be clearly shown by a simple experiment.

**Experiment 9.** Are there definite parts in the stem through which the liquid rises? (a) Cut off the stem or branch of a growing tree, such as a box elder or willow, and place the cut end in red ink. The next day cut across the stem and note where the red ink has been passing upward through the stem. Does the liquid rise in definite places or all through the stem?




FIG. 34. Fibrovascular bundles of a celery stalk.

(b) Repeat (a), using the stem of a lily, a wheat plant, or a corn plant. What difference do you note in these plants as compared with what you saw in the plant used in part (a)?

The experiment has shown that the liquid travels through definite parts of the stem. The tubes which carry the sap up through the stem are called *tracheal tubes*, and they are arranged in groups called *fibrovascular bundles*. They are really long cells with pits or holes in each end. In some trees these cells are several feet in length. Sometimes the end walls of the cells are broken down so that continuous tubes from ten to fifteen feet in length are produced. These holes allow the sap to pass from one cell to the other as the different forces move it upward to the leaves. In the plants you observed in part (a) of Experiment 9 (the box elder and willow), the fibrovascular bundles are arranged in a ring

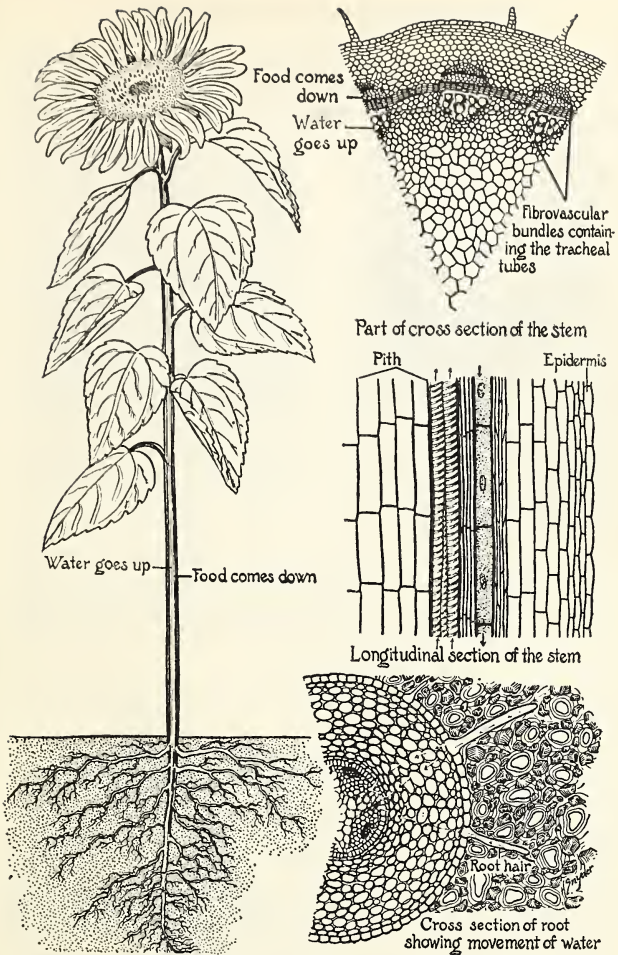


FIG. 35. These four drawings show the structure of the various parts of the plant which enable it to carry food throughout its system.

around the stem as shown in Figures 35 and 36. In the lily, wheat, and corn plants the bundles are distributed through the stem as shown in Figure 37. The tubes in the outer part

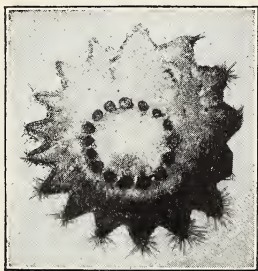


FIG. 36. Cross section of the stem of a cactus plant showing the fibrovascular bundles arranged in a circle. (Photo by G. D. Fuller.)

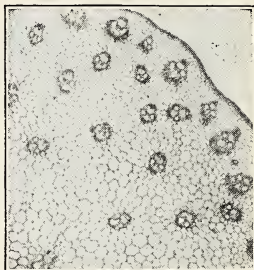


FIG. 37. Part of a sectional view of a corn stem showing the scattered fibrovascular bundles. (Welch Mfg. Co. photo.)

of the fibrovascular bundle carry food down, while those on the inner side of the bundle carry water and minerals up. As you will learn in a later unit, this difference in the arrangement of the fibrovascular bundles is one of the bases for classifying plants into groups.

The passage of the sap through the stem and the leaves can be shown by an experiment.

**Experiment 10. Where does the sap pass through the leaf?** (a) Obtain some leaves of lettuce or celery. Place the lower end of the stem of the leaf in some red ink. Examine the leaves after half an hour. Does the liquid pass through definite paths? (To insure clear results, the lettuce or celery should be crisp.)

(b) Obtain green leaves and examine them to see how the veins are arranged. Which of the leaves are parallel-veined (Figure 38), and which are net-veined (Figure 39)?

The sap in the veins passes through the walls of the veins into the cells in the interior of the leaf by the process of osmosis, of which you have already learned.

**Self-testing exercise 6.** Arrange the following terms in such order that they will show the route and the process through which water and minerals reach the leaf: tracheal tubes, osmosis, soil, roots, imbibition, root hairs, veins, fibrovascular bundles, interior of leaf. Osmosis and imbibition may be used as often as needed.

**How is the process of food manufacture carried on in the plant?** Exactly how the plant leaf manufactures food is not known, but scientists have learned enough so that we can understand the general nature of the process. But before we investigate this matter of how the plant makes its food, we must have clear in our minds what the scientist has discovered about the various kinds of food.

It is customary for us to classify the foods we eat as vegetables, fruits, nuts, and animal products. The scientist, however, classifies them on the basis of their chemical composition. According to his method, the foods manufactured by plants are grouped in three classes: *carbohydrates*, *fats*, and *proteins*. There are two common kinds of carbohydrates, namely, starches and sugars. Each of these food substances contains carbon, hydrogen, and oxygen, but protein contains also nitrogen, phosphorus, and sulphur. The exact nature of these foods and their uses will be discussed in Unit II. In this unit we are concerned with their manufacture.

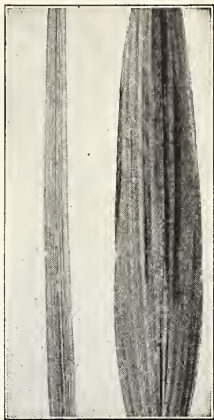


FIG. 38. Parallel-veined leaves of the palm.



FIG. 39. A net-veined leaf of the poplar.

Let us see by an experiment just what conditions are necessary in plants for the manufacture of carbohydrates to take place.

**Experiment 11. Under what conditions will leaves manufacture carbohydrates?** (a) Obtain two rapidly growing plants such as the geranium or the nasturtium. Place one in the direct sunlight. Place the other in a dark place. After several days examine the leaves of both plants. What change has taken place in the leaves of the plant which was kept in the dark?

(b) Cut a leaf from one plant while it is in the sunlight, and a leaf from a plant that has not been exposed to sunlight for some hours. Place the leaves in a dish containing alcohol. Allow them to remain until they are colorless. (The process can be hastened by heating.) Then place both leaves in a solution of iodine. If there is starch present, the iodine will cause the leaf to become purple. Examine the two leaves. Which contains the more starch?

(c) Cut off another leaf from each plant. Place each leaf in a small dish and cover with water. Cut the leaves into small bits while under water. With a small stone, grind the fragments of leaves so that the sap will be pressed from them. Allow the liquid in the dishes to stand for from 15 to 20 minutes; then pour off the liquid in each dish into a test tube. Add about 1 cubic centimeter of Fehling's solution to each tube, and boil. A greenish or a yellow-red color shows the presence of sugar. Results?

(d) Place the two plants in the sunlight again, and the next day test leaves of each plant for starch. Result?

(e) Place both plants in darkness for 24 hours and again test the leaves for starch.

*Note on part (a).* It might be better to grow one plant entirely in the dark, in which case the leaves will be white or yellowish white.

**Self-testing exercise 7.** What three conclusions can you draw from this experiment?

The green material which gives the leaf its color is called *chlorophyll*. To the naked eye, leaves appear to be solid green in color. Let us see what the microscope shows us about the source of color in leaves.

**Experiment 12.** How is the chlorophyll distributed through the leaf? (a) Obtain leaves of a lily, house leek, or Elodea and examine them under the low power of a compound microscope. Observe that the green chlorophyll is not distributed uniformly throughout the leaf.

(b) Make a thin cross section of a green leaf and mount it in a drop of water on a slide. Cover it with a cover glass and study it under the high power of a compound microscope.

As can be seen from the cross section of the leaf and examination of Figure 40, the leaf is not uniformly green; it gets its green color from the *chloroplasts* which are scattered in the cells. (Chloroplast is the name given to the special bodies that contain the chlorophyll.)

The cross section and Figure 40 also give us an idea of the internal structure

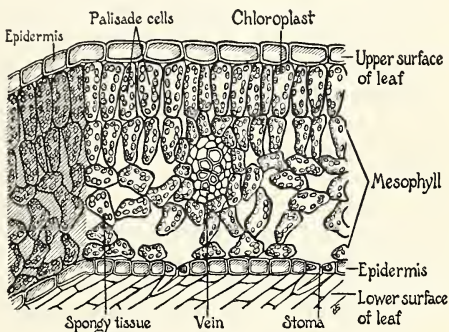


FIG. 40. Cross section of a lilac leaf under the high power of a microscope.

of the leaf. On the outside of the leaf, on both the upper and lower surface, is a layer of epidermal cells. These form an outer covering for the protection of the leaf. Between the lower and upper epidermis are the *palisade cells* and the *spongy tissue cells*, which together are called the *mesophyll* of the leaf. Here and there you can also see the ends of the veins as very, very small branches which bring the water and minerals to the leaf. Small openings in the epidermis, the stomata, allow air to enter the leaf.

When we think of a manufacturing plant, we picture in our minds a huge building with chimneys belching forth smoke

and hundreds of workmen engaged in operating various kinds of machines. In general, it is a picture of ceaseless activity amid the roar of whirring machinery. It is thus difficult to see how the common green plants could be the world's greatest factories; they do not present the same picture as the ordinary factory. But, they are like factories: They use raw materials, change them into new products, and in the process they require energy and machinery.

As we have seen, the process of food manufacture goes on in the leaf. Experiment 11 showed us that light and chlorophyll are necessary for the manufacture of starch. An understanding of the process of food-making depends upon an understanding of the part played by chlorophyll and by light. The light from the sun is one kind of *energy*; that is, it has the ability to do work. Heat, as you know, is another form of energy. When heat is applied to the boiler of a steam engine, it changes water to steam, and steam causes the wheels of the engine to turn. The source of the energy from the steam engine is thus the heat energy which is applied to the boiler. Light is also a kind of energy, and under certain conditions it can be put to work.

It has been found that when sunlight is passed through chlorophyll, certain of the rays which compose sunlight are absorbed. This means that a certain amount of energy has been taken from the sunlight by the chloroplasts. These rays furnish the energy that enables the chloroplasts to change the raw materials into carbohydrates. The chloroplasts may therefore be thought of as the machinery which is run by the energy of light. In this process the light energy is changed into a new kind of energy (chemical energy) which is stored in the manufactured food. The process of manufacturing carbohydrates from carbon dioxide and water under the influence of sunlight is called *photosynthesis*, which means putting together by means of light ("photo" meaning light and "synthesis" meaning putting together).

When the proper raw materials are provided and the plant

is placed in the sunlight, the factory in the leaf is ready to begin operation. To explain the processes which take place in the manufacture of carbohydrates, you must know some of the simpler facts of chemistry.

The earth on which we live, our buildings, automobiles, furniture, and ourselves are made of *substances*. It is the business of the chemist to examine these substances and discover what they are made of, what their characteristics are, and how they behave under certain conditions. Through experimentation the chemist has discovered that some materials cannot be separated into simpler materials. These he calls *elements*. For example, iron is an element; so also are gold, aluminum, copper, zinc, and sulphur. They can be broken into particles too small to be seen by the human eye or even too tiny to be distinguished by the most powerful microscope, but still they are not changed. They can be subjected to as high a temperature as man can produce, and still they will not separate into simpler materials. Each particle has the same *properties* as those of the larger mass.

On the other hand, there are certain substances which can be separated into simpler substances. These the chemist calls *compounds*. Sugar, for example, is a compound.

**Experiment 13.** Into what simpler substances can sugar be separated? Place a little sugar in a test tube and heat it over a flame. What do you find around the inside of the tube near the top? What remains in the bottom of the tube?

The black solid at the bottom is carbon, and the liquid at the top is water. But we have not yet discovered all the elements of which sugar is made, because the water which appeared is also a compound. Chemists have been able to separate it into two simpler materials, hydrogen and oxygen (Figure 41). Both of these substances are colorless gases. Hydrogen is very light in weight and has been used to inflate balloons. Oxygen, you know, is the gas in the air which under certain conditions causes burning to take place. Since

neither oxygen nor hydrogen nor carbon can be separated into simpler substances, they are elements. Thus we see that the compound, sugar, is made up of three elements—carbon, hydrogen, and oxygen.

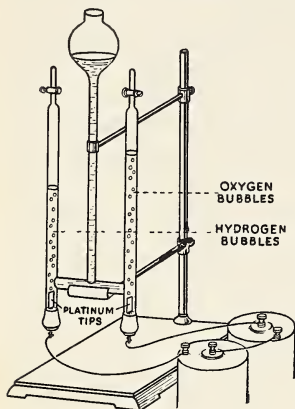


FIG. 41. By passing an electric current through water, the water is decomposed into the gases, hydrogen and oxygen.

Chemists are also interested in bringing about chemical changes and in discovering their nature. There are many kinds of chemical changes, but we shall discuss here only those kinds which are necessary to understand the process of food-making in plants. In the experiment showing the effect of heating sugar in a test tube, we have an illustration of one kind of a chemical change, that of *decomposition*. You remember that the sugar was separated into simpler materials, carbon and water. When materials are separated into simpler substances, the process is called

decomposition. This experiment also illustrates clearly the nature of a chemical change; namely, that this kind of change results in the formation of new substances which have different properties from those of the original substance. For example, sugar is a white solid which dissolves easily in water. When heated, it is decomposed into carbon and water. Carbon is a black solid which will not dissolve in water. Water is a colorless liquid. The white solid is thus changed chemically into a black solid and a colorless liquid. If an electric current is passed through the water, it can be decomposed into hydrogen and oxygen, both of which are colorless gases.

Another kind of chemical change takes place when two substances *combine* to form a new substance. For example, if

hydrogen is burned, it combines with oxygen and forms water. Water has properties entirely different from either hydrogen or oxygen: It is a liquid, which you can see, while hydrogen and oxygen are invisible gases. Furthermore, water will not burn, while hydrogen burns easily. Another result of this type of chemical change is our common table salt, which is made up of sodium and chlorine. Now the element sodium is a soft, bright, silvery, poisonous metal. The element chlorine is a yellowish-green poisonous gas. In combination these two elements form white crystals, which, far from being poisonous, are one of the necessities of life.

**Self-testing exercise 8.** Why are the following examples types of chemical changes? Decay of wood, souring of milk, digestion of food in the body, and spoiling of food.

Now, keeping clearly in mind what an element is, what a compound is, and the nature of the chemical changes, combination and decomposition, let us see how the green plant manufactures these two food substances, starch and sugar—compounds called carbohydrates.

First, what are the raw materials with which the plant must work? Water is one; carbon dioxide is the other. Both are compounds. Through the root hairs and roots, up the stem, and into the cells of the leaf comes the water. Through the tiny holes in the leaf, the stomata, comes the carbon dioxide in with air. Now the greatest factory in the world sets to work. The energy from the sun's rays furnishes the power, and the chloroplasts are the machines. In some wonderful way the green chloroplasts with the aid of the sun's rays bring about a combination of the carbon dioxide and the water into a new compound, a carbohydrate which we call sugar, made up of the three elements carbon, hydrogen, and oxygen.

In Experiment 11 you found starch in a green leaf after photosynthesis had been going on for some time. Sugar is probably formed first in the process, but it dissolves in the sap

of the cell. Practically as fast as sugar is formed, it is changed into starch in the cells. It is stored in the leaf or in some other part of the plant, such as the root, stem, or seed, until it is needed by the plant (Figure 42).

Even after years of patient study by trained scientists, we only partly understand just how the plant brings about these chemical changes. Recently an English scientist has been able to manufacture sugar from carbon dioxide and water. The sugar so produced, however, cost more than an equivalent weight in diamonds. The exact process of photosynthesis still remains one of Nature's great secrets. And yet, these carbohydrates constitute the most widely found class of foods upon which living things depend for their existence.



FIG. 42. Under a high-power microscope the cells with their stored starch grains look like this.

The exact details of protein manufacture by the plant are not known. Proteins are compounds containing nitrogen and usually small amounts of sulphur and phosphorus, in addition to carbon, hydrogen, and oxygen. Apparently there is no definite part of the plant which specializes in the manufacture of proteins. Proteins are formed by the combination of nitrogen, sulphur, and phosphorus with the carbohydrates. Neither light nor chlorophyll is necessary, and it is thought that any living cell may manufacture proteins. In most of the plants nitrogen, sulphur, and phosphorus enter the plant through its roots in the form of minerals. Certain plants, like clover, peas, and alfalfa, obtain their supply of nitrogen from the air.

Still less is known about the formation of fats by the plants. They contain the same three elements as the carbohydrates (carbon, hydrogen, and oxygen), but in different

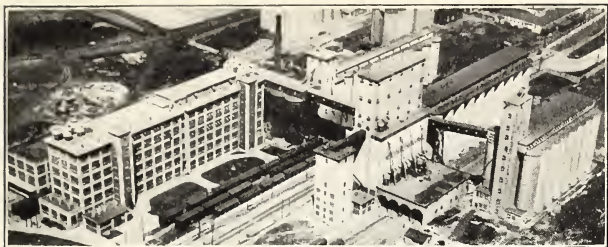


FIG. 43. This great flour mill is not really manufacturing foods. It is merely changing into usable form foods that have already been manufactured by the wheat plant. (Ewing Galloway photo.)

proportions. They are probably manufactured from the carbohydrates. Fats are stored in seeds and grains and are changed to soluble materials when needed by the plant. They may occur in either solid or liquid form in the cell. We obtain many vegetable oils, such as olive oil, cottonseed oil, cocoa-butter, corn oil, linseed oil, and cocoanut oil from plants.

**Where is the world's food supply manufactured?** Probably the first answer which comes to your mind is, "The world's food supply is manufactured in our mills, our canning factories, our sugar refineries, and other industrial plants of like character." If you will reflect a moment, you will find that each one of these factories starts with materials already in the form of foods. Grains, fruits, vegetables, meats, and dairy products furnish the raw products which are refined, preserved, stored, or changed into new products. Tracing back the source of food one step farther, we find that plants and animals are our sources of food. All animals, however, obtain their food either directly or indirectly from plants. Those animals which feed only on other animals of course get their food directly from animals, but the animals which they eat obtain their food from green plants.

Animals are unable to use for food the raw materials found in the air, the soil, and water. As a matter of fact, the green

plant does not use these raw materials for food, but it is able to take these raw materials and manufacture food from them which is usable by the plant. A great city with its thousands of factories and mills is truly a marvelous testimonial of man's progress in adapting the forces and materials of Nature to his uses. But the greatest industry in the world is carried on by Nature in the leaf of the green plant. The leaf of the green plant is really the factory in which the entire food supply of the world is manufactured.

**Self-testing exercise 9.** Make a table in which you will compare a green plant to some kind of a factory. Use the form that is shown below.

| PROCESSES AND MATERIALS    | PLANT | FACTORY |
|----------------------------|-------|---------|
| Raw materials              |       |         |
| Source of energy           |       |         |
| Principal parts of factory |       |         |
| Machinery used             |       |         |
| Products made              |       |         |
| How products are stored    |       |         |
| Uses of products           |       |         |

**How do plants which cannot manufacture food get their food supply?** It is clear from what you have just read that only plants which contain chlorophyll can manufacture foods. This wonderful substance, about whose workings we know so little, has a monopoly on the manufacture of carbohydrates, the basic foods. Yet, there are plants which contain no chlorophyll. From where does their food come? The answer is that they, like the animals, must find food that has already been manufactured by green plants.

Can you think of any plants that are not green? You have all seen mushrooms and puffballs. Notice also the plant shown in Figure 44. These plants belong to a class

known as *saprophytes*. They obtain food from decayed or dead plants and animals or from food materials manufactured by man from plants and animals. You are probably familiar with one of the common plants of the saprophyte variety, the *bread mold*. Let us examine some bread mold under the microscope in order that we may see its structure.

**Experiment 14.** How does bread mold come in contact with its food supply? (a) Moisten a slice of bread. Expose it for half an hour to the air, preferably in a kitchen or in some other warm place. Place it in a fruit jar or dish so that the bread will remain moist, and keep it in a warm place. Examine it from day to day. What happens?

(b) Remove the bread from the dish and examine the mold. Notice the tiny threads, *hyphæ*, which form a delicate, tangled network (*mycelium*).

The bread mold gets its food through certain of these hyphæ which grow down into the bread. The food passes into the cells of the hyphæ by the process of osmosis (page 26) just as the water and minerals pass into the root hairs. But remember this important difference: The root hairs are taking in materials to be manufactured into foods; the hyphæ are taking in foods that were manufactured by some living, green plant. Bread mold is but one of the many kinds of molds. Molds grow on leather, paper, canned fruits, meats, in fact, on nearly every substance from which they can extract food. Not all of these plants have special parts for getting food. The yeast plant, for example, is simply a single cell. The food of the yeast plant passes directly through the walls of the cell by osmosis.

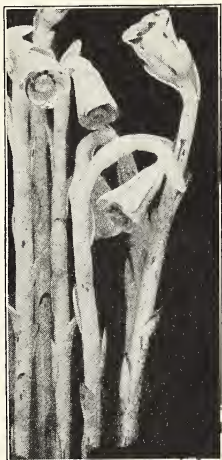


FIG. 44. Indian Pipe  
(Field Museum photo.)

There are also many plants which obtain their food from living green plants. These are called parasites. One of the commonest plants of this kind is the dodder, which can be

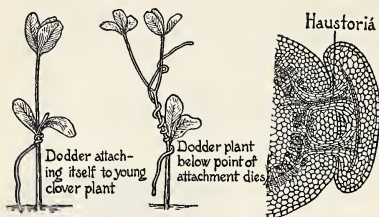


FIG. 45. How the dodder plant gets its food.

recognized by its yellow leaves and yellow twining stems. Its seed develops into a new plant just like other plants, but the upper portion of the stem, if it comes in contact with the stem of another plant, twines itself around this twig and sends sucking root-like growths, or haustoria, into the twig (Figure 45). Through these haustoria it obtains both food and water. If its upper stem does not encounter the twig of another plant, the dodder dies after a few weeks. Smuts, rusts, mildews, and blights, so injurious to many of our food crops like potatoes, apples, and wheat, are also parasites.

Many plants obtain their food from living animals; that is, they are animal parasites. A certain kind of water mold gets its food from the bodies of living fishes. This mold often causes great damage to fishes. Perhaps the commonest plants of this sort are the bacteria (Figure 47).

These exceedingly small parasites are found in all animals. Some of them are helpful to the animal in assisting the process of digestion, and some of them are harmful, causing diseases. Like other parasites,



FIG. 46. Perhaps you have seen these shelf-like parasitic growths on trees. They are called fungi. (Geo. T. Hillman photo.)

they get their food from the host (the animal upon which they feed) by the process of osmosis. They cannot make their own food, as the green plants do.

**SUGGESTED ACTIVITY.** Find as many dependent plants as you can at home or in the woods. Make a list of the different kinds which you find and of the kinds of material upon which you find them growing. If you do not know the name of the plant, bring it to school and show it to your teacher.

**Self-testing exercise 10.** Compare independent plants with dependent plants.

**Self-testing exercise 11.** If we compare plants and animals in regard to the food-getting problem, we find that in many respects their problems are alike, and in some respects they are unlike. Compare the food problem of plants and animals. In doing this, first decide the bases on which you are going to compare them. For example, the need for food is one basis of comparison.

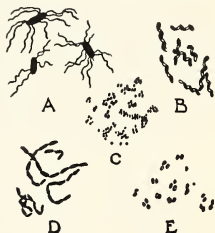


FIG. 47. Various kinds of bacteria: (A) typhoid, (B) tuberculosis, (C) pus forming, (D) nitrogen-fixing, (E) common in water.

### ADDITIONAL EXERCISES

1. From your general observation of the habits of animals, supply additional illustrations for each of the methods employed by carnivorous animals in getting food.

2. Take a field trip to a near-by vacant lot or woods. Observe insects and other animals eating. Catch the animals and also secure some of the food which they eat. Bring the animals to class or take them home. Observe how they eat, and write as detailed a report as you can of their method.

3. Observe domesticated animals, such as the cat, dog, horse, cow, pig, sheep, duck, pigeon, or chicken. Write a detailed report describing how they eat and drink.

4. Some plants, such as Venus's flytrap, the sundew, and the pitcher plant, are carnivorous. Prepare a report on carnivorous plants. Make drawings to show how they capture their food.

5. Visit a zoo at feeding time and observe how different kinds of animals eat.

6. Some animals, such as the bee, ant, beaver, and squirrel, store food. Find how and where they store their food.

7. Insects vary widely in their methods of getting food. Write a report on the different methods used.

8. Make a list of the food materials in a piece of pie. Then give the story of how each food material was produced, manufactured, transported, etc., in order that it might be made available to you.

9. Write a short paper on "Characteristic Foods of Other Lands." Your paper should include some explanation of why these particular foods are so commonly used in those lands.

## UNIT II

### HOW DO LIVING THINGS USE FOOD?

#### PRELIMINARY EXERCISES

1. The kinds of foods which animals eat depend upon such factors as those listed below. Choose any wild animal you wish as an example, and show whether or not each factor helps to determine what the animal eats.

- (a) The kind of animal
- (b) The season of the year
- (c) The age of the animal
- (d) The kind of environment
- (e) The structure of the animal
- (f) The kind of food eaten by its parents
- (g) The kind of food that is available

2. Most food eaten by animals must be broken into small pieces before it can be digested. State two reasons why this is true.

3. Below you will find listed the different processes through which food passes in the human body before it is available to the cells. Write these processes in the order of their occurrence.

Acted upon by the pancreatic juice

Broken into small pieces by the teeth

Absorbed by the blood vessels in the walls of the intestine

Acted upon by the gastric juice

Circulated through the body by the blood

Acted upon by the saliva

Passed through the walls of the blood vessels to the lymph

Absorbed by the cells of the body

4. State four purposes which food serves in living things.

5. In your notebook copy the words listed below. Place a plus sign (+) after the name of the body parts used to excrete waste materials, and a minus sign (—) after those not so used.

|         |         |       |       |                 |       |
|---------|---------|-------|-------|-----------------|-------|
| heart   | liver   | brain | eyes  | large intestine | skin  |
| kidneys | stomach | nose  | mouth | sweat glands    | lungs |

6. The words listed below will be used in this unit. Write definitions for those whose meaning you understand.

|             |           |            |           |
|-------------|-----------|------------|-----------|
| respiration | enzyme    | vitamin    | lenticel  |
| calorie     | villi     | protoplasm | hibernate |
| mammal      | capillary | diffuse    | digestion |
| duct        | lymph     | spiracle   | tissue    |

7. Below is a series of ten statements, some of which are true and some of which are false. Write the numbers of the statements, and place a plus sign (true) or a minus sign (false) after each number according to whether the statement so numbered is true or false.

1. We should chew food only because chewing makes it taste better.
2. Foods are sometimes cooked to prevent them from spoiling.
3. The stomachs of animals are organs in which some of the food is stored for later use.
4. Digestion is a process which goes on in cells of higher animals.
5. Animal foods need not be digested by human beings, because they are composed of the same elements as those that make up the human body.
6. Foods are changed chemically in the process of digestion.
7. The same blood stream carries both food materials and waste materials.
8. Water is classed as a food.
9. Food is more important to man than air and water.
10. Some foods are more easily digested than others.

## THE STORY OF UNIT II

Unit I has given you the idea that all living things, whether plant or animal, spend much time taking food. Why does the organism need food? What happens to the food taken by living things?

Perhaps you have noticed by the side of a stream or in a field a great smooth boulder that seemed out of place. There were no other rocks around it, or it was a different kind of stone from others near by. You may have wondered where it came

from and how it got there. Of one thing you may be sure: The stone did not bring itself there; it was brought by some outside force such as a glacier, a landslide, or running water. And if you should watch this boulder every day for the rest of your life, you would never see it do anything by itself. It would not eat, move, or make a noise. It would just lie there. In some respects it is like a plant or animal; it has weight, it occupies space, it is made of certain materials. If you were asked to state the most important difference between this stone and an animal, you would probably say, "The animal is alive, while the stone is not." If you were asked to explain "life," you would probably find it difficult to give a satisfactory explanation. What life is we cannot say, but we do know that living things can carry on certain activities, while non-living things cannot. If you were asked what kinds of activities living things carry on, what would your answer be?

It is because living things carry on activities that they need food. The stone does not need food; it has nothing to do; there is nothing it can do. You and I, and the other living things in the world, on the other hand, are ever in a state of activity because the conditions under which we live are such that we must constantly be doing something in order to keep alive. All of these activities of living things cannot continue many hours without a supply of food.

You have heard of persons who, lost in the forest or desert without food supplies, became so weak that they could not walk or even crawl. In some of these cases of near starvation



FIG. 48. The horse and its rider are using up tremendous stores of energy which food must provide.

a little food soon brings the persons back to the ability to move and to carry on other activities. The food in some way gives the energy or power to move about and do the things which normal persons do. How does the food furnish the



FIG. 49. In the bodies of these baby warblers the worms and insects brought by the mother will be changed to provide materials for feathers, muscle, bone, and other tissue. (L. W. Brownell photo.)

energy needed for activity? Are foods used by living things only to supply energy? We shall see, in Problem 1, just what a food is in terms of what it does for living things.

If you looked at a part of your flesh or nail or bone under a microscope, you of course would not expect to see little bits of potato, oatmeal, ice cream, or bread. And yet, these may be some of the foods you eat. Surely the food you eat must be changed by the body before it is made into human blood, bone, muscle, and nerves. You recall from Unit I that plants take carbon dioxide, water, and minerals and change them into carbohydrates, wood, cork, bark, and other materials. Just how do living things change food so that they can use it in the various ways needed to carry on their activities?

Many persons know so little about their own bodies that they believe the food is used by the stomach and the intestines. This is, of course, not true. The food is used by the millions of tiny cells of which the body is composed. Cells, however, cannot go for their food, and it is therefore necessary that

the body have a method of delivering it to the cells. This is true not only of man but also of other living things. You will find, as you study the problems of this unit, that different kinds of living things have their own methods of bringing this about.

When the food reaches the cells, chemical changes take place in it, depending upon the uses to which it is put. As a result, certain waste products, such as carbon dioxide and ashes, are produced. In other words, living things are somewhat like machines. A machine such as the steam engine requires coal to produce steam. As the coal burns, it produces wastes. If these wastes are not removed, the fire will go out. In the bodies of living things, wastes must also be removed, or the efficiency of the body will be lowered. To understand this process of waste removal you must be able to answer two questions: (1) What kinds of wastes are produced in the body? and (2) How is each kind of waste removed?

The problems which you will solve in this unit will provide you with the answers to the questions raised in this Story. Before you begin to study, think of other problems which you would like solved and see if they too cannot be answered.

#### PROBLEM 1: WHAT FACTORS DETERMINE THE KINDS OF FOOD NEEDED FOR LIFE?

##### **What characteristics must a material possess to be a food?**

**STUDY SUGGESTION.** In the following paragraphs is a description of the activities and processes of living things which make food necessary. When you have finished reading these paragraphs, you should be able to make a definition for food which will include all the uses foods serve in living things.

Observation of the activities of animals leaves one with the impression that the kinds of activities in which they engage are limitless. Animals can run, swim, climb, fly, bark, whistle, talk, kill, search for food, play, fight, eat, drink,

and pursue or flee from their enemies. All of these activities are dependent upon the movement of wings, fins, legs, tails, or other external parts of animals. In addition to these external movements animals also carry on processes within their bodies which require movements of their internal structures. For example, the muscles of the heart, as well as the muscles which control breathing and the action of the stomach and intestines, are in a state of constant motion. This power of independent movement is one of the characteristics in which living things differ from non-living things.

If you will observe the world around you, you will find it full of moving things. Clocks, automobiles, boats, elevators, locomotives, motors, street-cars, clouds, windmills, streams, smoke, and many other things are in constant motion. None of these things can move, however, unless the force of steam, of exploding gas, of electricity, of gravity, or of some living thing sets it in motion. That is to say, some force, some form of energy, is always necessary to produce movement. This is true for living things as well as for mechanical things. If you will try to push a stick into the ground any great distance, you will see that a great amount of energy is needed. When a tree forces its roots through the soil or sends its hundreds of pounds of trunk and branches into the air, energy is used. So too, when animals move about, energy is used by the muscles to move the legs, fins, wings, or other parts which make possible running, walking, flying, swimming, and climbing. Other movements in the body, such as those of the heart and breathing, also require energy.

The body has often been called the "human machine." Let us consider the human machine in relation to some machines with which we are familiar. The steam engine gets its energy from burning coal and air, the gasoline engine from burning or exploding gas mixed with air, and the electric motor from electricity produced by a generator run by water power or by power from burning coal. In living things the energy must also come from some source outside the body.

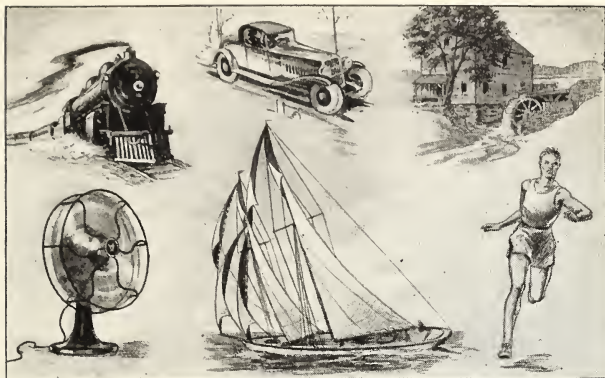


FIG. 50. Every moving thing must have a source of energy to produce movement. What produces the energy for each of the objects in this picture? Can you trace each form of energy back to the sun?

A living thing cannot go on moving for a long time without a new supply of materials to use as a source of energy. The sources of energy for living things are those materials which we call foods. They serve the same purpose in the body of a living thing as the fuel oil or coal in a steam engine. How energy is obtained from food is a problem which you will solve later in the unit.

One should not get the idea from the preceding paragraph that the food taken into the living thing is used only to produce energy. Let us again consider the steam or electric engine. Every time one of these engines moves, there is a certain amount of wearing away of the materials of which the engine is made. In the steam engine the terrific heat alone is a cause of wear. Almost constantly machinists must keep at work repairing broken parts and replacing worn-out ones. So, too, with the human machine, because of its ceaseless movement or activity, there is a constant wearing away of the body materials. These must be replaced. But the human machine is its own machinist. It is more than a machinist;

it is a chemist. The human machine takes some of the food which goes into its body and builds it up into new materials to replace those which are being broken down by its ceaseless activity. We may therefore add another answer to the ques-

tion of our problem—another part of the definition of food. How will you state it?

Another process which requires certain materials is that of growth. When you first came into this world, you probably weighed less than ten pounds and were not over twenty inches in height. Today you may be ten times as heavy and three times as tall. If you observe the rest of the living world, you will discover that you are not the only living thing which can grow. A grain of corn becomes a tall plant in a few months, and a little puppy soon attains the size of its parents. Growth, as you will see in a later unit, is brought about by increase in the size of cells and the addition of new cells in the body. Any substance which can be used to build new living material is a food.



FIG. 51. Food furnished the materials for the stalks, leaves, and other parts of this giant corn plant which began life as a small seed.

You have just read that among the foods used by living organisms there must be those that contain certain building materials. We cannot clearly understand what these needed building materials are unless we know what the living organism is made

of. If you are going to make a model airplane or bake a cake, you must know what materials to use.

Let us pause, then, and ask the chemist to analyze for us a living organism. Let us see what it is made of; then we can better understand what building materials must be contained in food. We shall take the human body as an example. Table 1 shows us how the chemist analyzes the

TABLE 1. COMPOSITION OF A 150-POUND MAN

| ELEMENT         | PER CENT | POUNDS  | CUBIC FEET |
|-----------------|----------|---------|------------|
| Oxygen.....     | 65       | 97.5    | 1081.00    |
| Carbon.....     | 18       | 27.0    | .11        |
| Hydrogen.....   | 10       | 15.0    | 2642.50    |
| Nitrogen.....   | 3        | 4.5     | 59.90      |
| Calcium.....    | 2        | 3.0     | 0.03       |
| Phosphorus..... | 1        | 1.5     | 0.21       |
| Potassium.....  | 0.35     | 0.525   | 0.009      |
| Sulphur.....    | 0.25     | 0.375   | 0.002      |
| Sodium.....     | 0.15     | 0.225   | 0.003      |
| Chlorine.....   | 0.15     | 0.225   | 1.11       |
| Magnesium.....  | 0.05     | 0.075   | 0.0006     |
| Iron.....       | 0.004    | 0.006   | 0.00001    |
| Iodine.....     | traces   |         |            |
| Fluorine.....   | traces   |         |            |
| Silicon.....    | traces   |         |            |
| TOTAL.....      | 99.954   | 149.931 | 3784.87461 |

human body. His analysis shows not only the elements of which the body is composed but also the approximate quantity of each element.

If a chemist could make a man (of course, he cannot), he would need the volume of materials shown in the third column of Table 1 to produce a man weighing 150 pounds. He would need a room containing 3785 cubic feet (about 16 feet long, 16 feet wide, and 16 feet high) just to store the materials. The space which this man would occupy when he was completed would be about 2.5 cubic feet. It does not seem possible for 3785 cubic feet of materials to be built into a body containing but 2.5 cubic feet. It must be remembered, however, that these materials do not exist in the body in the form of elements, but in the form of compounds. For example, of the 112.5 pounds of oxygen and hydrogen in the body, more than half exist in the body combined as water. The oxygen and hydrogen as gases would occupy over 3000 cubic feet. As water, they occupy only about 1.6 cubic feet. This may be clearer to you when you know that

1700 cubic inches of steam occupy only about one cubic inch of space when in the form of a liquid (water).

Thus we see just what our muscles, skin, bones, hair, nerves, etc., are made of, and we know that our bodies cannot build new living material unless our food contains these elements.



FIG. 52. This circle graph shows the approximate proportions of the various elements that make up a 150-pound person.

Some of these elements are probably familiar to you, while others are not. All of them are supplied to the body by the air, the water, and foods. We are composed, then, of elements like those in the materials of our surroundings. It is because these elements are combined into compounds that we cannot recognize them separately.

This, then, is the wonder of life: Living things can take non-living substances into their

bodies as food and build them into living materials.

For many years foods were defined as those substances from which new living materials could be manufactured, or which supplied a source of energy. Experimentation in the last fifty years has extended this definition of food. It has been discovered that certain materials are necessary because a lack of them results in certain diseases. For example, one of these materials is necessary to cause the bones to develop properly in young children. Another of these materials is necessary to secure normal growth. These materials are called *vitamins*. There is not a great deal known about these materials at the present time, but because it has been proved that they assist in the regulation of the life processes, they are classed as foods.

A substance to be classed as a food does not necessarily have to possess all of the characteristics which have been mentioned. For example, one substance may be necessary to

regulate certain body activities and not be a source of energy. Or a substance may supply energy and not be usable for the building of new body material. It is classed as a food if it possesses one of the characteristics mentioned.

It is also true that there are substances possessing one or more of the characteristics mentioned, which are not classed as foods. Such a substance is alcohol. Alcohol might be classed as a food because it can be used as a source of energy. It has been shown, however, that alcohol is harmful to the organism. For this reason it is not classed as a food. In formulating your definition of food, you must therefore include as part of your definition that the substance must not be harmful to the organism.

**Self-testing exercise 1.** Make a definition for food. Begin your definition, "A food is any substance which . . .," etc.

**What are the uses of the different classes of food?** **STUDY SUGGESTION.** In the paragraphs which follow is a description of the different classes of food. Refer constantly to the definition which you made of food to see why each material named is a food.

In Unit I you were told that the chemist has classified all foods according to their chemical composition. From what you have just read about the make-up of a living organism, you can see why this chemical classification is necessary. The physician, or other expert who advises people what to eat, cannot think only in terms of beefsteak, carrots, ice cream, and apples. He must know whether these different foods contain the elements which the body machine needs to overcome its weaknesses and to carry on its activities in a normal way. So, if you are going to be intelligent in this matter of foods, if you are going to understand what you read in books, magazines, and newspapers about proper eating, you must understand the chemist's classification of foods.

This manner of thinking about your foods may be new to you, but you have already been affected by it. While you were a baby, you were carefully fed so much of this and so

much of that. Even now you are probably told that you should eat spinach and carrots, that you must not eat too much candy, and various other things about your diet. Why? Because scientists have found just what these foods contain and what purposes they serve in keeping you healthy.

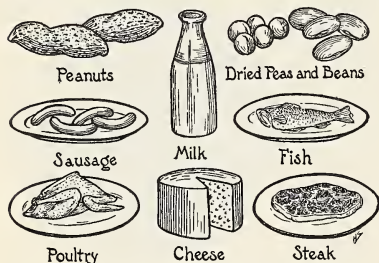


FIG. 53. Foods that are rich in protein.

You have already learned that three of the classes of foods are carbohydrates, fats, and proteins. Certain other materials—water, minerals, and vitamins—are also classed as foods. No matter whether your food be custard or carrots, beef or broccoli, nuts or noodles, it is made up of some or all of these basic food substances. Each of these six different classes of foods is necessary to carry on the activities and life processes of living things.

Protein is the only food material containing nitrogen, which is one of the essential elements in building *protoplasm*, the living material of the body. Protoplasm is a jelly-like, almost colorless substance contained in the cell, and is the living material of which living things are composed. The protoplasm in living things is the substance which carries on the activities of life. Like other materials it wears out and must be replaced. In addition to nitrogen, protein contains other elements, such as carbon, hydrogen, oxygen, phosphorus, and sulphur, also used in building protoplasm. When more protein is eaten than is necessary for building purposes, the excess protein may be used as a source of energy. Its main purpose, however, is not that of supplying energy; it should be thought of as the main source of materials for the construction of protoplasm. Some of the foods that are rich in protein are shown in Figure 53.

Carbohydrates, composed of carbon, hydrogen, and oxygen, are generally classed as fuel foods because they are used mainly as sources of energy. They also take some part in growth and self-repair. You have already learned that two kinds of carbohydrates are starch and sugar. The commonest sources of starch in our daily diet are potatoes and cereals, or products manufactured from cereals. Sugar is generally eaten in the form of cane sugar, fruit sugar, corn sugar, or beet sugar. If more carbohydrates are eaten than are necessary for fuel requirements, they may be changed to a material called *gly-*

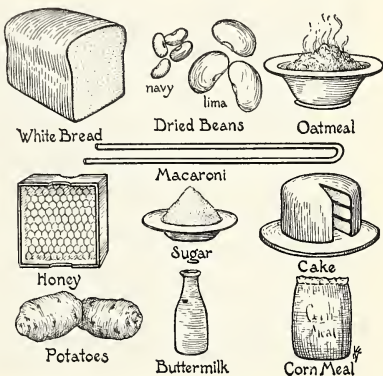


FIG. 54. Foods rich in carbohydrates.

*cogen* and stored in the cells of the liver and the muscles for future use. This stored food may later be used for energy if it is needed. In addition to these uses, carbohydrates are believed to assist in changing the fats so that they may be used by the body. Some foods rich in carbohydrates are shown in Figure 54.

Fats contain the same elements as carbohydrates, but the proportion of elements in the two classes of compounds is different. There are many different kinds of fat. Some are found in meats, some in milk, and some in plants. Some foods containing a high percentage of fats are shown in Figure 55. Fats are fuel foods, a given quantity of fat supplying about twice as much energy as the same amount of carbohydrate or protein. Like the carbohydrates, fats may be stored in the body and used as a reserve food. In

addition to these uses it is generally agreed that fats are necessary to maintain the proper conditions in the intestines so that certain chemical changes necessary in the digestion of other foods can take place. As a rule fats are stored in the cells under the skin, between the muscles, and around the different organs of the body.

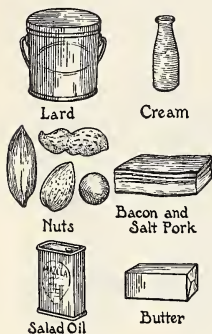


FIG. 55. Fat foods.

necessary for life are those containing calcium, potassium, phosphorus, sodium, sulphur, magnesium, iron, chlorine, and iodine. Each is needed in carrying on the life-processes and in building the body.

Foods with calcium and phosphorus compounds are fed to babies and young children because these substances are necessary for the building of teeth and bones. (Study Figure 57 and read carefully the description below it.)

Iron helps the blood to carry oxygen throughout the body. Iodine aids in regulating body processes. Experimentation

Mineral salts have also been mentioned as foods. They are compounds containing two or more elements. Common table salt, for example, is a mineral salt containing sodium and chlorine. Mineral salts cannot be used as a source of energy, as can the other foods, but they are just as important in keeping the living organism working properly. The minerals absolutely

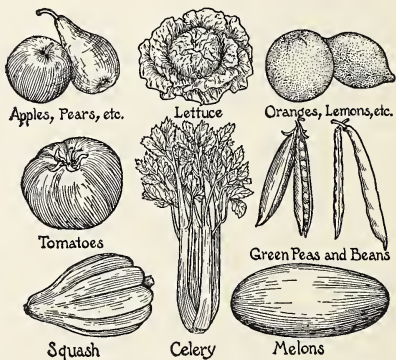


FIG. 56. Some foods containing minerals.

has also shown that mineral salts assist in the digestion of food, keep the heart beating at a constant rate, aid in osmosis, and help form a blood clot to prevent the loss of blood from wounds. Some of the foods which are important sources of minerals are shown in Figure 56.



FIG. 57. Crooked teeth developed in a goat because of faulty mineral diet. Note that the lower teeth (A) cannot properly meet the upper teeth (B). The dark spots in (B) are holes made in the roof of the mouth by the failure of the teeth to come together. (Cornell University Animal Nutrition Laboratory.)

Water is classed as a food because in so many ways it is needed to carry on the activities of living organisms. Water is necessary to assist in changing food materials so that they may be used by the body, to assist in the elimination of the waste materials left over from the process of digestion, and to provide the fluid of the blood. From the figures given on page 55, you recall that of a one-hundred-fifty-pound man, about fifty-seven pounds are water.

For a great many years it was believed that the classes of foods just described were sufficient for normal growth. The discovery and proof of the existence of a new class of food materials, the vitamins, presents one of the most fascinating

examples of research in recent years. Several lines of investigation have been followed, only one of which will be considered here. People living in the Orient, where the diet is mainly fish and polished rice, have for thousands of years been afflicted with a disease called beri-beri, which causes intense pain in the legs and arms, and sometimes results in paralysis and death. Director-General Takaki of the Japanese Navy reported that the average number of cases treated for beri-beri was 323.5 per thousand per year. In 1896, Eijkman, a Dutch scientist, discovered that chickens fed exclusively on polished rice developed a disease similar to beri-beri. At his suggestion, data were collected from inmates of prisons who were fed on different rice diets. The results are shown in Table 2. These

TABLE 2. RELATIONSHIP OF BERI-BERI TO THE KIND OF RICE USED FOR FOOD

| KIND OF RICE                     | NO. OF PRISONERS | NO. OF BERI-BERI CASES | PERCENTAGE |
|----------------------------------|------------------|------------------------|------------|
| White rice.....                  | 150,266          | 4201                   | 2.7        |
| Rice with partial silver skin... | 35,082           | 85                     | .2         |
| Unpolished rice.....             | 96,530           | 9                      | .009       |

data show conclusively that the skin of the rice contains some material which prevents beri-beri. Further study showed that the "silver skin" of the rice contained a hitherto undetected material. To this material, the name "vitamin" was given.

Studies in more recent years have definitely proved that there are several kinds of vitamins, each of which has an important part to play in the processes of living things. To distinguish the vitamins from each other, each vitamin is indicated by a letter, such as vitamin A, vitamin B, etc. Figure 59, on page 64, shows some of the foods which contain the different vitamins.

The lack of vitamin A in the diet results in a decreased rate of growth, the drying up of the tear glands, and a general lowering of the resistance to disease. Experiments have

shown that it is especially important that young animals obtain this vitamin in their food. The vitamin was first discovered in butter-fat and egg-yolk. It is also present in many other foods, as shown in Figure 59. It is destroyed by long heating in the presence of air.

In fact, heating foods at high temperatures frequently destroys their value. Notice the two white rats shown in Figure 58. The rats were originally the same size and were fed on the same foods. However, the food of one was dried at a very high temperature. Its value was thus destroyed, and the rat failed to develop into a healthy individual. The food of the larger rat was dried at a low temperature. Its nourishing value was not injured, and the rat grew in a healthy, normal way. In the ordinary cooking to which our foods are subjected, however, very little destruction takes place.



FIG. 58. Effect of destroying proteins by too great heat. (Cornell University Animal Nutrition Laboratory.)

The lack of vitamin B results in a stoppage of growth. Experiments with young rats have shown that if this vitamin is removed from their diet, a general decline will follow, resulting in death before eight days. Recent experiments seem to indicate that vitamin B is not a single vitamin but a mixture of two vitamins. Both of these vitamins, however, are needed in the everyday diet, so that for ordinary purposes no distinction need be made. The richest source of vitamin B is probably yeast, although, as is indicated in Figure 59, it is found in other foods. In the grains it is found chiefly in the outer coats. Removal of this coat, such as takes place when rice is polished and when wheat is used in the production of white flour, eliminates most of this vitamin. For this reason many

diet experts advise that people should eat whole-wheat bread, which contains this vitamin. However, white-flour bread may be used, provided the vitamin is obtained from some other food.

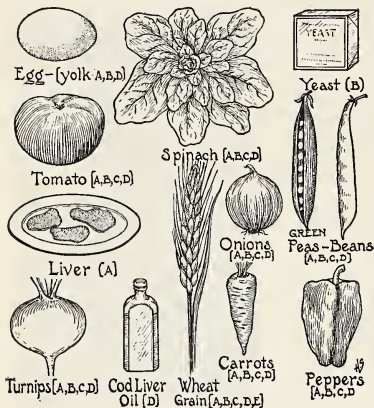


FIG. 59. Foods containing vitamins.

Little is known about the function of vitamin C in animal bodies. It has been shown, however, that the lack of this vitamin in the food supply results in a disease called scurvy, which destroys the tiny blood vessels of the body. This disease has been known for over a thousand years. It was very common during long trips on sailing vessels, where for many months no fresh vegetables nor animal foods could be obtained. We now know that this disease is caused by the lack of vitamin C in the diet. This disease may be prevented or cured by such foods as orange and tomato juice, celery, carrots, lettuce, and watercress. Vitamin C is destroyed by heating the food in contact with air; thus raw fruits and vegetables should be eaten to provide it.

Vitamin D is necessary to secure the proper growth of bones and teeth. Lack of it produces a disease called rickets, in which the hardening of the bones of growing children is interfered with. This may result in bow-legs or knock-knees, and in severe cases, death. Vitamin D is most abundant in cod-liver oil, although it has been found in butter-fat and egg-yolk. In recent years it has been discovered that vitamin D can be produced in the body by the action of certain rays of sunlight. Children treated with these rays or with foods

which have been treated with this ray have been completely cured of rickets.

In addition to vitamins A, B, C, and D there are three other known vitamins. Vitamin E, found in the oil from



FIG. 60. This pig obtained plenty of mineral foods for bone formation, but her diet lacked vitamin D. Therefore she developed such a case of rickets that she could not stand on her front legs. Daily doses of cod-liver oil restored her to the normal condition illustrated at the right.

wheat, apparently affects reproduction. Experiments have shown that animals produce a fewer number of young if this vitamin is withdrawn from their diet. Vitamin F and vitamin G are the names given to the two vitamins which were formerly thought of as being but one vitamin, namely, vitamin B.

At the present time it is impossible to say that all of the vitamins have been discovered. In all probability there are vitamins essential to the living organism which as yet have not been identified. Much more experimentation is also necessary to establish definitely the effects of the vitamins which have been discovered. Since plants are the sources of vitamins, it is probable that they serve some important function in the plant. There is at present no evidence of the function served. But enough evidence concerning the need of vitamins for animals has been gathered to show that vitamins are exceedingly important in maintaining the general health of the animal body.

In recent years many food manufacturers have advertised their products as being rich in vitamin content. The advertisements sometimes read as if the more vitamins one eats, the healthier he will be. This, of course, is not true. Lack of a sufficient quantity of vitamins may be harmful to the body, but eating more than is necessary does not make a person any healthier.

**Self-testing exercise 2.** For each class of food write a statement that will give the reason why it is a food. For example, "Protein is a food because . . .," etc.

**What are the principles which must be followed in selecting foods?** **STUDY SUGGESTION.** Before you begin to study, make a list of the principles you already know that should guide one in selecting foods. As you study, keep note of the new ideas which you find about selecting foods.

In the previous sections of this problem it has been shown that food must provide the body with material for carrying on the various activities and life processes in which the living thing engages. In addition to this it has been shown that different classes of food serve different purposes in the body. Regarding the selection of food, the conclusion can therefore be made that one's diet should include all classes of foods. It should include foods which supply materials for building protoplasm, foods from which energy can be obtained, water, and the foods which assist in the regulation of the life processes. The foregoing statements apply not only to man but to other living things as well. In the discussion which follows, man is chosen as the example to show the principles which should be followed in selecting food. The same principles, as you will see in Unit VII, are used by man in feeding his farm animals.

Another consideration in the selection of food is the quantity one eats. It is evident that enough food must be eaten to supply the materials necessary for growth, self-repair, and energy. It is of course very difficult for an individual to

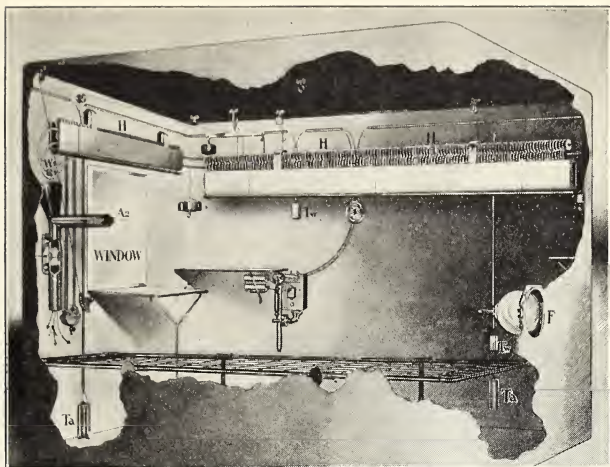


FIG. 61. By means of this apparatus, called a *respiration calorimeter*, it is possible to measure the exact amount of heat given off by the body. Other types of calorimeters are available which permit individuals to carry on certain types of work which call for the expenditure of much energy. Through these experiments it has been found possible to determine the food requirements for individuals doing different kinds of work. (Photo by the Nutrition Laboratory of the Carnegie Institution of Washington.)

determine just how much food he should eat. The amount necessary depends upon many factors, such as age, weight, the kind of work one does, the season of the year, etc. Certain standards, however, have been worked out by scientists which furnish a general guide as to the amount of food needed. These standards are subject to considerable modification to adapt them to the needs of each individual.

The standards which have been made are the result of careful investigation and experimentation. Through the use of very complicated apparatus (Figure 61) it is possible to determine the amount of energy required to perform the normal activities of life. The amount of energy required is expressed

in *calories*, a calorie being the amount of heat required to raise the temperature of one kilogram (about 2.2 pounds) of water one degree centigrade.\* Some of the standards which have been determined are as follows:

|   |                       |
|---|-----------------------|
| Man, active muscular work . . . . .                               | 3500 calories per day |
| Man, light muscular work . . . . .                                | 3150 calories per day |
| Boy of 15 years . . . . .   | 3150 calories per day |
| Boy from 13 to 14 years and girl from 15<br>to 16 years . . . . . | 2800 calories per day |
| Boy of 12 and girl from 13 to 14 years. .                         | 2450 calories per day |
| Boy from 10 to 11 years and girl from 10<br>to 12 years . . . . . | 1800 calories per day |

The table above shows the number of calories of energy required by the human body. As has been previously pointed out, this amount varies to some degree, depending upon the needs of the individual. In order to determine how much food is needed, it is necessary to determine the energy or *fuel value* of the different foods. This is done by burning the food to determine the amount of heat produced by a given quantity. The fuel value of foods is then expressed in terms of so many calories per pound. For example, a pound of butter produces 3410 calories when burned; this is therefore given as the fuel value of butter. In order to determine how much food should be eaten, it is only necessary to determine the number of calories of energy needed by an individual and then select the foods which will supply that amount. The fuel value of many foods is given in Table 3.

So, from what you have just read, you can see that both the kind of food and the quantity of food must be taken into consideration in the selection of foods. The solution to the problem, "What shall I eat?" is thus very hard to find. It is certain that the appetite is not always a safe guide to follow, and that neglect of the proper diet may cause trouble some-

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\*The physicist uses two kinds of calories: the small calorie, which is the amount of heat required to raise the temperature of one gram of water one degree centigrade, and the large calorie, which has just been defined. The large calorie is used to express the energy value of foods.

TABLE 3. AVERAGE PERCENTAGE COMPOSITION OF COMMON AMERICAN FOOD PRODUCTS

| FOOD MATERIALS        | WATER | PROTEIN | FAT  | CARBOHY-<br>DRATES | MIN-<br>ERALS | FUEL<br>VALUE PER<br>POUND |
|-----------------------|-------|---------|------|--------------------|---------------|----------------------------|
| Beef, sirloin steak.. | 54.0  | 16.5    | 16.1 |                    | .8            | 1100                       |
| Beef, round.....      | 60.7  | 19.0    | 12.8 |                    | 1.0           | 890                        |
| Veal, leg.....        | 60.1  | 15.5    | 7.9  |                    | .9            | 625                        |
| Pork, loin.....       | 41.8  | 13.4    | 24.2 |                    | .8            | 1245                       |
| Ham, smoked . . .     | 34.8  | 14.2    | 33.4 |                    | 4.2           | 1635                       |
| Chicken, broilers..   | 43.7  | 12.8    | 1.4  |                    | .7            | 305                        |
| Fish, perch.....      | 50.7  | 12.8    | .7   |                    | .9            | 275                        |
| Eggs, hen.....        | 65.5  | 13.1    | 9.3  |                    | .9            | 635                        |
| Butter.....           | 11.0  | 1.0     | 85.0 |                    | 3.0           | 3410                       |
| Milk, whole.....      | 87.0  | 3.3     | 4.0  | 5.0                | .7            | 310                        |
| Cheese, cream.....    | 34.2  | 25.9    | 33.7 | 2.4                | 3.8           | 1885                       |
| Bread, white.....     | 35.3  | 9.2     | 1.3  | 53.1               | 1.1           | 1200                       |
| Crackers, soda . . .  | 5.9   | 9.8     | 9.1  | 73.1               | 2.1           | 1875                       |
| Beans, string.....    | 83.0  | 2.1     | .3   | 6.9                | .7            | 170                        |
| Beans, dried.....     | 12.6  | 22.5    | 1.8  | 59.6               | 3.5           | 1520                       |
| Cabbage.....          | 77.7  | 1.4     | .2   | 4.8                | .9            | 115                        |
| Peas, canned.....     | 85.3  | 3.6     | .2   | 9.8                | 1.1           | 235                        |
| Tomatoes.....         | 94.3  | .9      | .4   | 3.9                | .5            | 100                        |
| Potatoes.....         | 62.6  | 1.8     | .1   | 14.7               | .8            | 295                        |
| Apples.....           | 63.3  | .3      | .3   | 10.8               | .3            | 190                        |
| Bananas.....          | 48.9  | .8      | .4   | 14.3               | .6            | 260                        |
| Oranges.....          | 63.4  | .6      | .1   | 8.5                | .4            | 150                        |
| Dates, dried.....     | 13.8  | 1.9     | 2.5  | 70.6               | 1.2           | 1275                       |
| Raisins.....          | 13.1  | 2.3     | 3.0  | 68.5               | 3.1           | 1265                       |
| Peanuts.....          | 6.9   | 19.5    | 29.1 | 18.5               | 1.5           | 1775                       |
| Chocolate.....        | 5.9   | 12.9    | 48.7 | 30.3               | 2.2           | 2625                       |

time during one's life. Perhaps the best solution is to consult the school nurse or a physician.

Two well-known investigators in the field of nutrition make the following statements regarding the selection of foods:\*

The results of scientific investigation support the view that if one will obey the following three precepts regarding the selection of food, a diet will be secured which will be highly satisfactory for the preservation of vitality and health.

(1) Everyone should take daily throughout life approximately the equivalent of a quart of milk. Some of this may be taken as a

\*E. V. McCollum and Nina Simmonds, *Food, Nutrition, and Health*. Published by the authors, East End Post Station, Box 25, Baltimore, Md.

beverage, or in ice cream, creamed soups, creamed vegetables, custards, buttermilk, etc.

(2) Once a day take a liberal serving of greens or pot herbs. These should be cooked. These include such leafy vegetables as lettuce, romaine, watercress, cabbage, brussels sprouts, chard, kale, spinach, turnip tops, beet tops, dandelion leaves, etc.

(3) Twice each day a salad should be eaten. A salad according to definition is a preparation of herbs, vegetables, or fruits, lettuce, celery, watercress, etc., usually dressed with salt, vinegar, and pepper; or a dish of chopped meats or fish mixed with oil, vinegar, and other components.

It is of course understood that these suggestions do not make up the entire diet; they do, however, indicate certain foods which should be made part of the daily diet. The rules stated above apply to most persons, but certain individuals may require special examination to determine the kinds of food best for them.

Man not only applies what he has learned concerning foods in the selection of the foods which he eats, but he also applies the same principles in his care of animals. Agricultural experiment stations have determined the best kinds and proper quantities of foods required to keep animals in good health. Thus farmers have been able to fatten their stock for market in a much shorter time, and increase the milk production of cows and the egg production of hens. How man applies these principles will be considered in Unit VII.

**Self-testing exercise 3.** Table 3 lists some of our common foods and shows the different classes of food materials which they contain. Make a list of the ten foods which contain the largest percentage of protein. Make a similar list of those foods which contain the largest percentage of carbohydrates, of fats, and of minerals. Refer to Figure 59, which shows the presence of vitamins in certain foods. List five sources of each of four of the vitamins shown in the illustration.

Place your results in a table. Then examine the table and underline the foods with a high protein content which you include in your daily diet. Do this also for the other classes of foods. On

the basis of this list do you find that you include the necessary classes of foods in your daily diet? (Reference to Figures 53 to 56 will help you.)

**Self-testing exercise 4.** State the reasons for the practices regarding the selection of food which you listed under the study suggestion on page 66.

## PROBLEM 2: HOW IS FOOD PREPARED FOR USE BY LIVING THINGS?

**What is the basic structure of all living things?** In order to understand how food is prepared for use by living things we must examine more fully the fundamental structure of living things. Robert Hooke, an English microscopist, is usually given credit for first observing, in 1665, what he called the "little boxes or cells" of a plant. He had examined some thin sections of cork and found them to look much like a honeycomb but not so regular in structure. Other scientists were also using microscopes at this time, trying to explain the structure of living things. It was not until about 1838 that two German friends, Matthias Jacob Schleiden, a professor at the University of Jena, and Theodor Schwann, a professor at the University of Berlin, came upon the idea that both plants and animals are composed of tiny, living cells or units.

They, however, had not gone far enough in their study to realize that inside the cells of both plants and animals is a living, jelly-like substance. Dujardin, a professor at the University of Rennes, in 1835 had observed this substance in animal cells and had called it *sarcode*. Von Mohl, a German physiologist, had observed it in plant cells and had called it *protoplasma*, meaning "first molded form." Then, in 1861, Schultze, a professor at the University of Halle, Germany, and often called the father of modern biology, stated that the units of organization of all living matter are little masses of protoplasm around a *nucleus* (meaning nut or kernel), and that this protoplasm or living substance is much the same in both plants and animals.

**Experiment 15.** What is the structure of plant and animal cells? Examine with a microscope such plant cells as those of the onion, Elodea, Nitella, privet, and Spirogyra. Use Figure 63 to help you find the various parts of the cells. If you stain the

cells with iodine, methyl blue, or fountain-penink, the nucleus and other parts will be readily seen. Directions for preparing the slides will be given by your teacher.

Examine with the microscope such animal cells as the amœba, the paramecium, the cells obtained by scraping the inner lining of the mouth, red blood corpuscles, cells from a callus on your finger, cells from the skin of a frog, and the red-blood cells of a frog. Stain the cells.

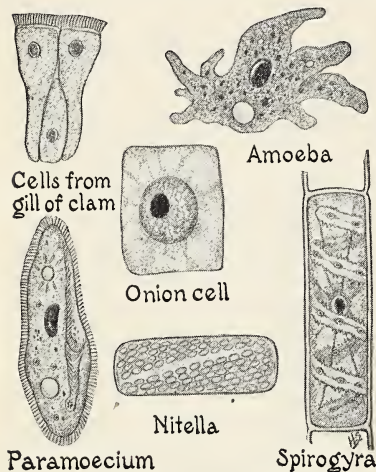


FIG. 62. All living things are made up of one or more cells. Foods must enter the cells before they can be used.

cells which you have examined, you will see a cell wall of some kind. In the plant cells the cell wall is quite thick, and contains a material called *cellulose*. In animal cells there is no real cell wall, but the cell is usually enclosed in a plasma membrane. This membrane is present also within the cell walls of plants.

Inside the cell wall or membrane is the protoplasm. This is made up of a denser round or oval part, called the nucleus, which is often near the centre, and the remainder of the protoplasm outside the nucleus, which is called the *cytoplasm*. The cytoplasm is composed of minute granules floating in a fluid-like substance. Here and there, especially in young

In the typical cell, shown in Figure 63, as well as in most of the

cells and in plant cells are clear spaces, called *vacuoles*, filled with cell sap. Floating in the cytoplasm are granules of food, droplets of water and oil, and crystals, but these are often too small to be seen with the ordinary microscope.

Not only do the cells of different plants and animals have different structures, but we also find that different cells in the same plant or animal differ. You recall the kinds of cells in a green plant, such as epidermal cells, palisade cells, root cells, spongy cells, and guard cells. (See page 35.) An animal, likewise, has different cells. Living cells vary in size as well as in shape, but it is surprising to find that

the cells which make up the mouse are not much different in size from those which compose the elephant. Most cells are so small that it would require from 3000 to 5000 placed side by side to make a string of cells one inch long. There are probably some single-celled animals and plants which are too small to be seen with the best microscope. Certainly our bodies must contain millions upon millions of cells! Figure 64, page 74, shows some of the cells found in the human body. Examine the figure carefully.

Did you notice when you examined the cells from the inside of your cheek or in the onion skin (Experiment 15) that there were many cells attached to each other? Cells of the same kind joined together in this way form *tissue*, such as, skin tissue, muscle tissue, nerve tissue, bone tissue, and woody tissue. Tissues in turn are grouped together forming *organs*, that is, structures which have special work to do in the life of a complex organism. Thus, roots, leaves, and stems are organs of plants; eyes, hearts, lungs, and ears are organs of animals.

In a one-celled organism like the amœba or paramecium (Figure 62) the single cell does all of the work of the body.

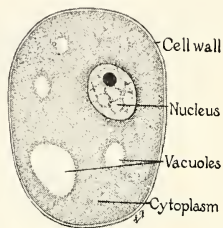


FIG. 63. Parts of the cell.

It must take in food, build it into new living material, excrete waste products, breathe, circulate the food materials to different parts of the cell, and produce other living things of the same kind.

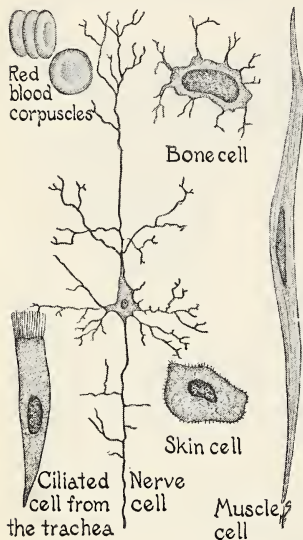


FIG. 64. Various kinds of cells of the human body.

In organisms which contain many cells, certain kinds of cells do certain kinds of work for the body as a whole, but still each cell must do all of the things that a one-celled organism does. A muscle cell, for example, aids the body as a whole to move; however, each muscle cell must be able to take in food, use it for energy, build it into new living material, and excrete wastes. So you see that the work of the body is really done by the cells which compose it.

**What change must take place in food before it can be used by a living thing?** **STUDY SUGGESTION.** It is neither necessary nor desirable that you try to remember the methods em-

ployed by different animals in preparing food for use. From your study of these different animals you should discover the two general methods which are employed and the different kinds of structures which assist in bringing about the digestion of food.

From what you have just read, you can understand that the food we eat must find its way into the millions of tiny cells that make up the living organism. It is in the cell that the food is put to the various uses which you studied earlier in this unit. In Unit I you learned how the jelly-like amoeba gets food into its single cell; it simply flows along and

surrounds its food. The one-celled paramecium, you learned, is a little better equipped; it has a hole or mouth in its one cell. Unlike the paramecium, however, the cells which compose complex living things do not have mouths through which the food may pass into the cell. Nor can they, like the amoeba, wrap themselves around food and thus take it in. Cells are entirely surrounded by the plasma membrane. This means that the food must pass through this membrane before it can be used by the cell.

Therefore, in order to understand how living things are able to use food, we must first learn how the food gets into the cells. Obviously, some very marked changes must take place in the meat, apples, potatoes, nuts, and other food materials that we eat before they can pass into a cell so tiny that it can only be seen through a microscope. In Unit I you learned that under certain conditions materials actually can pass through a membrane wall. Experiment 5, page 26, showed you that water passed inward through the membrane of the egg, and the molasses solution passed outward through this membrane to the water. You learned that the plant really got minerals from the soil through the walls of the root-hair cells.

Some foods can pass readily through membranes; certain sugars and minerals can do so. The great majority of foods, however, cannot do so. They must first be changed by the organisms. This process of changing food so that it may be absorbed by the cells of the organism is called *digestion*. When you begin chewing a morsel of food, you are starting a series of "break-ups" which continue steadily until that food is reduced to such condition that it may pass through the membranes of the cells. Turn back to page 40, Figure 42, and notice the starch grains stored in the cells of a potato. These grains cannot pass through the membranes of the cells. They must first be made soluble; that is, they must be changed chemically into a substance which can dissolve and pass through the membrane.

The nature of digestion can be understood to a certain extent by performing an experiment with starch, as described below.

**Experiment 16. How is starch digested?** (a) Prepare an egg as in Experiment 5, page 26, filling the egg with a mixture of starch and water. You may use a pig membrane instead of the egg. Allow it to stand for several days; then test the water in the tumbler for starch by adding a few drops of iodine solution. If starch is present, a blue color will appear. On the basis of your results do you conclude that starch can or cannot pass through the membrane?



FIG. 65.

(b) Repeat (a), filling the egg with a solution of grape sugar in place of the starch. Test the water in the tumbler for grape sugar. This may be done by pouring a little of the water into a test tube, adding a small amount of Fehling's solution, and then boiling the mixture. If grape sugar is present, the color will change from a blue to a green or a reddish color. On the basis of this experiment do you conclude that grape sugar can or cannot pass through the cell walls of the membrane?

(c) Drop a small piece of starch into a test tube about half-full of water. Shake vigorously, add some *saliva*, and place the tube in a beaker of water. Prepare another test tube containing starch and water to which no saliva has been added. Place this test tube beside the other in the beaker of water. Keep the temperature of the water at about 98.6 degrees Fahrenheit for about 20 minutes (Figure 65). If a thermos bottle is available, it may be used. The two test tubes can be suspended in the bottle by strings.

Test the contents of both test tubes for grape sugar. What effect does the saliva have upon the starch? Refer to page 38 and explain why this is called a chemical change. Why should the temperature of the water be kept at about 98.6° F.?

(d) Chew a piece of unsalted cracker or bread until it is thoroughly wet with saliva. Note the sweet taste. Explain.

The process of digestion takes place in all living things. If you watch the food particles in a paramecium, you will notice that the food is gradually broken up, that its outline becomes less and less distinct, and that finally it disappears. It has been changed chemically and dissolved by certain digestive juices in the paramecium. In the more complex animals there are many different kinds of digestive juices, such as saliva, gastric juice, bile, pancreatic juice, and intestinal juice. These juices are manufactured in *glands* (Figure 66). The cells which compose these glands absorb certain materials from the blood and manufacture digestive juices from them. These digestive fluids are poured through tubes or *ducts* into the various tracts of the digestive system.

Experiment 16 showed that starch is changed into grape sugar by the action of saliva. This change is typical of the action of the other digestive juices. Some act upon cane sugar, some on fats, and some on proteins, all of them steadily carrying on the work of changing the materials so that they may be absorbed by the cells. In some of these juices there are one or more substances called *enzymes*, which have the power of causing a chemical change to take place in certain food substances, and thus assist in digestion. The enzymes themselves are not used up in the process of digestion; therefore a very small quantity of an enzyme is all that is necessary to cause a chemical change in a large quantity of food. Saliva is poured into the mouth from

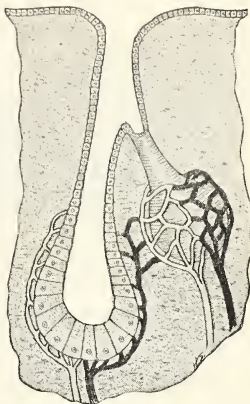


FIG. 66. At the left is a section view of a gland. Notice the cells that line the cavity of the gland, and the opening, or duct. *Capillaries*, as shown at the right, bring blood containing materials which are taken out by the glands to manufacture secretions.

three pairs of *salivary glands* (Figure 67). It contains an enzyme called *ptyalin* which has the power of causing insoluble starch to change to soluble sugar. It was the ptyalin which caused the change you noticed in Experiment 16.

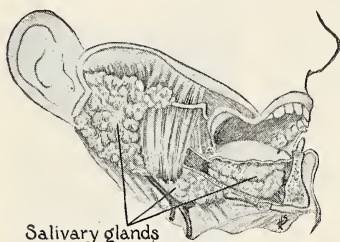


FIG. 67. Location of the three pairs of salivary glands.

*Gastric juice* is manufactured by glands in the walls of the stomach (Figure 68) and acts chiefly upon the proteins, which are broken up into simpler materials. It contains hydrochloric acid, which helps make the food soluble, and an enzyme called *pepsin*, which acts upon proteins.

*Pancreatic juice* is produced by the pancreas, from which it is carried to the intestines by a duct. Pancreatic juice contains three enzymes: *Trypsin* acts upon the proteins; *amyllopsin* changes starch to sugar; and *lipase* changes fats into materials which can be absorbed. This juice thus continues the process of digestion. *Bile*, which is manufactured by the liver and poured into the intestines, assists in the digestion of fats. The walls of the small intestine contain glands which produce *intestinal juice*; this assists in the digestion of sugar and proteins.

Somewhat similar digestive processes take place in plants, which, like animals, manufacture certain enzymes. This is seen in a grain of corn when it is beginning to grow. The seed contains an enzyme called *diastase*.

**Experiment 17.** What effect does diastase have upon the food stored in a seed of corn? (a) Scrape the covering from a grain of corn; add a drop of iodine to the remainder. What food is indicated?

(b) Grind a grain of corn in a mortar as fine as possible or obtain some corn meal. Test for starch with iodine and test for sugar with Fehling's solution (see Experiment 16). Results?

(c) Place a pinch of the ground corn in a test tube and add about

10 cc. of water. Heat it to boiling and allow it to cool. Divide into two parts. To the first portion add a few cc. of Fehling's solution and boil. Is sugar present?

(d) To the second portion, add a little diastase. Allow it to stand for half an hour after warming the contents of the tube slightly. Test the contents for sugar. Result?

(e) Obtain some germinated seeds of corn and test them for the presence of sugar by cutting them in small pieces, grinding them in a mortar, and then testing with Fehling's solution. Results? Compare with results obtained in (c).

The starch present in the seed cannot be used until it is digested. When the seed is kept moist and warm, the starch is slowly changed to sugar by the diastase. The sugar which is

produced can pass to the growing cells in the roots and stems and supply the material necessary for the growth of the cells. Even the smallest plants, like the bacteria, contain enzymes which act on foods and change them so that they may be absorbed and supply material for the growth of the organism. In fact, every plant, like every animal, has some digestive juices which serve to make food usable by the organism.

**How do the structures of animals assist in the digestion of food?** As you have just seen, digestion takes place mainly through a process of chemical change brought about by the digestive juices with their enzymes. In certain very interesting ways, the structures of animals help in these changes. Let us first see how the structures of animals help speed up the chemical changes which must take place in food before it can be absorbed by the cells. The rate at which a chemical action takes place is influenced by many factors, one of which is shown in Experiment 18, on the next page.

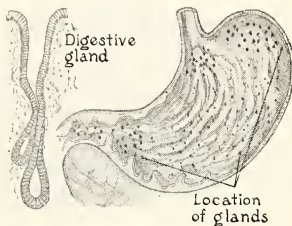


FIG. 68. The black dots indicate the approximate location of the gastric glands in the stomach. They are so tiny that they are hardly visible to the eye. At the left is shown a gland, highly magnified.

**Experiment 18.** How can the rate of chemical change be increased? Obtain two pieces of limestone about the same size. Break one piece with a hammer into many small pieces. Place the large piece in one beaker and the small pieces in another beaker.

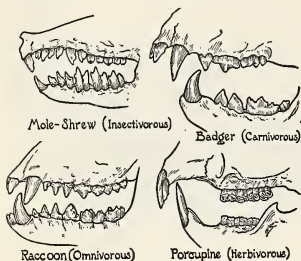


FIG. 69. Note the flat grinding teeth of the plant-eating porcupine, and the sharp, tearing teeth of the meat-eating badger.

Add an equal quantity of ten per cent hydrochloric acid solution to both beakers at the same time. What evidence is there that a chemical change is taking place? Compare the amount of time required to dissolve the large piece of limestone with the amount of time required to dissolve the small pieces of limestone. How do you explain the difference in the time required?

The experiment shows that the rate of chemical change is increased when the material is

broken up into small particles. Many animals possess parts which enable them to break the food into smaller bits and thus enable the digestive juices to come in closer contact with the food. Animals equipped with sharp claws, beaks, bills, and mandibles frequently tear the food into bits before they take it into their bodies. The *mammals* are well equipped with teeth with which they can cut, tear, crush, and grind the food which they eat (Figure 69). The teeth vary in shape, each kind being used for a different purpose. *Herbivorous* animals (that is, animals feeding solely on plants) are equipped with teeth which differ from those of the *carnivorous* animals. Vegetable foods must be chewed more thoroughly than meat, because they are harder to digest. By the use of these structures many animals prepare the food so that it may be acted upon more readily by the digestive juices.

Other parts of the body, such as the stomach, intestines, or gizzard may also assist in the separation of the food into small particles. The walls of the stomach and intestines

contain many layers of muscles (Figure 70). Contraction and relaxation of these muscles keep the food in a constant state of motion, which helps to divide the food into smaller particles and mix it with the digestive juices. The effect is similar to that produced by filling your hand with a mixture of water and crackers and then alternately closing and opening your hand until the cracker becomes a pulpy mass. If you open the gizzard of a chicken, you will find many small stones which

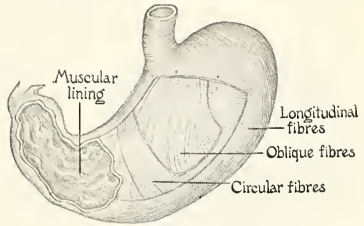


FIG. 70. Muscles of the stomach.

the chicken has swallowed (Figure 71). The walls of the gizzard contract and relax, and the stones are moved around, grinding the food into small bits. Many animals are thus equipped with special parts which help prepare their food for digestion.

**SUGGESTED ACTIVITY.** Make a collection of gizzard stones of chickens, turkeys, guinea fowls, and ducks. Compare them as to amount, size, shape, and kinds of materials.

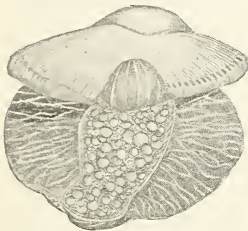


FIG. 71. A chicken gizzard split open to show the stones.

As you have already learned, the kind of food an animal eats is closely related to the structure of the animal. The earthworm has no teeth and thus cannot use nuts for food. The squirrel is equipped with sharp teeth and can easily extract and cut up the kernel from the hard shell of a nut. The sheep is a grass-eater.

The teeth of a sheep are large and flat-topped and are well suited for grinding tough foods. Furthermore, the whole digestive apparatus of the animal is so constructed that it can digest the kind of food it eats.

The stomach of the sheep has four different cavities (Figure 72). The grass is not chewed as soon as it is taken into the mouth, but passes directly down into the first cavity. Here it is soaked, rolled into small balls, and then passed upward

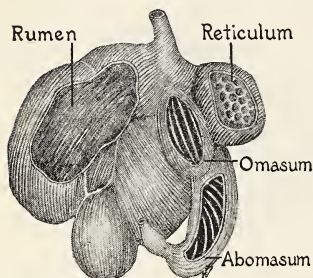


FIG. 72. The sheep's food goes first to the *rumen*, then back into the mouth for chewing. From there it passes into the *reticulum*, then into the *omasum*, and finally into the *abomasum*, where it is acted upon by gastric juices.

to the mouth, where it is chewed. After it is chewed thoroughly, it goes to the second and third cavities for storage, and thence to the fourth stomach, where it is acted upon by digestive juices in much the same manner as in the intestines of man. In this way the sheep is able to extract the necessary food from the grasses.

All of the animals which feed exclusively upon plants have complex digestive systems and long intestines (Figure 73). The intestines of an

ox are about 150 feet in length. Vegetable foods require a much longer period of digestion than animal foods, and a greater quantity is needed to supply nourishment. The long intestines of grazing animals are thus fitted to digest this kind of food because they supply a place of storage for the food while it is being acted upon by the digestive juices. The whole digestive apparatus of the lion, which feeds upon animals, is different from that of the sheep and other herbivorous animals. The lion has sharp, tearing teeth which can tear and cut flesh but cannot grind foods, as is necessary to obtain food from the grasses. Its intestines are but three times the length of its body; therefore the time consumed by the passage of food through the intestines would probably be too short to allow for thorough digestion and absorption of raw vegetable foods. Birds, worms, fishes,

snails, frogs, snakes, in fact all animals, feed upon foods which their structures enable them to digest and use.

**Self-testing exercise 5.** State evidence to show that the kinds of food which animals eat are closely related to the structures which they possess to digest their food.

### PROBLEM 3: HOW IS THE DIGESTED FOOD DISTRIBUTED TO THE CELLS?

**How is food distributed in the lower forms of plants and animals?** **STUDY SUGGESTION.** The descriptions which follow show that the distributing systems of animals vary from the most simple types to very complex types. As you study, note the increase in complexity of these systems.

We have now seen how the food that living things take into their bodies is reduced by the process of digestion to such form that it can be absorbed by the cells. You know that it must get into the cells, because it is the cells which actually perform the work of the body. The next important step in the use of food is its distribution to the various parts of the living organism.

Your feet and head are quite some distance from your stomach and intestines, where digestion takes place. Yet the muscles, nerves, and other tissues of the head and feet must have food. The leaves of a tree, where the tree's food is manufactured, may be many feet from the roots and the trunk; yet the roots and trunk must have food. Living things must have some transportation system so that food can reach the cells of every part.

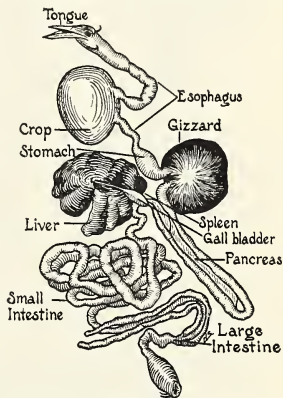


FIG. 73. Digestive apparatus of the chicken.

The distribution of food in the lowest forms of living things, that is, those composed of a single cell, like the amœba (Figure 74), is a very simple process. Many of these single-celled plants and animals live in a liquid environ-

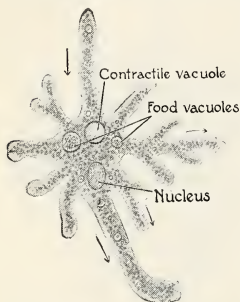


FIG. 74. The *food vacuoles* are merely bits of food being absorbed. The *contractile vacuoles* swell up and suddenly contract to excrete waste materials.

ment, that is, they are completely surrounded by water or another liquid. These liquids contain some food already in solution, and in such form that it may readily pass through the cell wall of the organism. Food thus passes into the living thing at all points of its outer surface. Once inside the cell the food *diffuses*, that is, mixes with the contents of the cell. Bacteria, for example, living in the intestines of man, absorb their food directly from the dissolved food in the intestines.

In simple plants composed of many cells, like the bread mold, the process of distributing food is a little more complex than in one-celled organisms. The bread mold (see Experiment 14, page 43) manufactures an enzyme which is given off by the hyphæ. This enzyme digests some of the bread with which it comes into contact so that it can be absorbed through the wall of the hyphæ. Although the bread mold is composed of many cells, the cells are not separated from each other by definite membranes. The digested food, once it enters the plant, thus passes by diffusion to the various parts of the plant. Because of the smallness of the plant, no special system of distributing food is needed.

In animals composed of many cells the distribution of food is a more complex process. The hydra, a small, fresh-water animal from one-eighth to three-fourths inch long and one-sixtieth inch in diameter (Figure 75), affords an interesting

example of the increase in complexity which is found in a multi-cellular animal. The hydra is different from the one-celled animals in that it has a cavity within its body. This enables the food to be brought into contact with the many cells which line the cavity. This inner layer of cells pours out a fluid which digests the food. These same cells absorb the digested food, keep what they need, and the remainder is passed on to the other cells by the process of osmosis.

If we examine the digestive and distributing apparatus of the earthworm, we find a decidedly more complex system (Figure 76). The earthworm has a tube, or *alimentary canal*, running through the length of its body with an opening at each end. The food passes into the mouth, thence through the pharynx to the *crop*, where it is stored temporarily. In the gizzard the food is ground into smaller pieces, and it then passes into the intestines. The cells lining the intestines manufacture a digestive fluid which is poured into the intes-

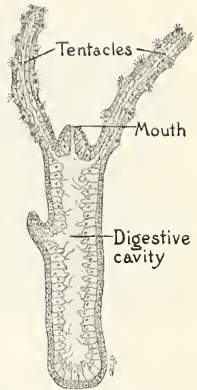


FIG. 75. Sectional view of the hydra.

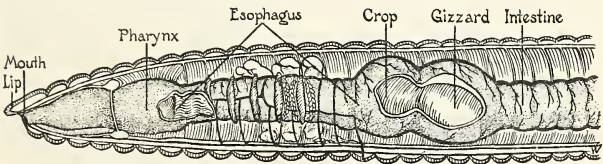


FIG. 76. Digestive apparatus of the earthworm.

tines. These cells also absorb the dissolved food. The earthworm has blood vessels filled with blood into which the digested food passes from the cells that line the intestine. The walls of these blood vessels contain muscles which drive the blood by alternately contracting and relaxing. The food

is thus distributed to all parts of the body. The digested food diffuses through the walls of the blood vessels so that each cell is bathed in a liquid. From this liquid the cells take up

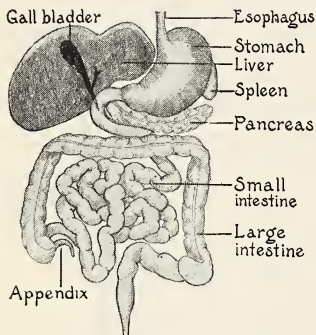


FIG. 77. Digestive system of man.

the food in the same manner as the one-celled organisms which you have studied. Thus you see that the earth-worm differs from one-celled organisms in that it is equipped with special parts for digesting food and distributing it to the cells.

**How is food distributed in the higher forms of animals and plants?** As an example of a higher form of animal, we will study the digestive and distributing apparatus of

man (Figure 77). If you were asked what it is that carries food to all parts of your body, what would you say? Perhaps you would guess "the blood." If you did so, you would be correct. The blood stream is the great transportation system of the human body. Through a marvelous network of *veins*, *arteries*, and *capillaries* the blood flows in a constant stream to every tissue and organ. Now let us see how this digested food gets first into the blood and then into the cells.

In our study of digestion we traced the food into the stomach and the intestines. In the small intestine, a tube about twenty-two feet long, digestive juices complete the work of making the food soluble, so that it can pass through the thin walls of the intestine into the blood. The area of the small intestine exposed to the absorption of food is greatly increased by the *villi*, small fingerlike projections from the wall (Figure 78). These villi in man number about 10,000 to the square inch. A section of a villus shows the presence of

minute blood vessels, the capillaries, and also other small vessels, the *lacteals*. These vessels have very thin walls, and (by the process of osmosis), they absorb the digested food which comes in contact with them.

The lacteals absorb the fats, and the capillaries absorb the other food materials. The lacteals unite into larger and larger vessels to form the *thoracic duct*, which connects with the blood stream through the *jugular vein*. The capillaries also unite to form large blood vessels, the veins, which carry the blood to the heart. The heart acts as a pump and forces the blood into the arteries. These arteries divide and subdivide into smaller and smaller

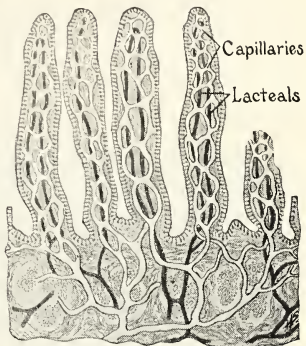


FIG. 78. Section view of villi.

blood vessels until they form capillaries which penetrate to all parts of the body. The walls of the capillaries are very thin and allow the liquid part of the blood containing the digested food to pass through them. This liquid is called *lymph*. Because the red corpuscles cannot pass through the walls of the capillaries, the lymph is colorless. The lymph surrounds the cells of the body (Figure 79), and it is from the lymph

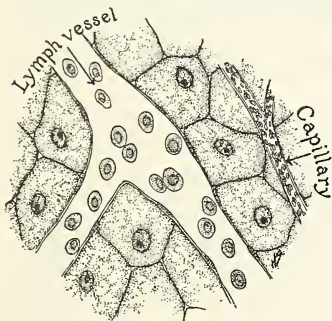


FIG. 79. Floating in the lymph are white corpuscles, which, as you will learn later, help the body fight germs.

that the cells obtain their food. The higher animals differ from each other in some of the details of structure of their

distributing systems, but in general the process is the same in all of them.

The higher plants differ from the higher animals in the distribution of food in that they have no organs which drive the food through their bodies. They possess special parts, the fibrovascular bundles, in which the food passes through the body, but the forces which keep the sap moving are mainly those of osmotic pressure and imbibition. There are probably still other forces which aid these two, but they are not as yet well enough understood by biologists to be discussed here. Animals are of course much more active than plants, and consequently they need a more abundant supply of food at all times to furnish energy. The rapid movement of the blood through the body of an animal insures an abundant supply of materials to the cells. In plants the movement of the sap is comparatively slow, but it is rapid enough to furnish materials to the growing parts.

**Self-testing exercise 6.** Arrange the following list of animals in the order of complexity of the structures they possess to distribute food: hydra, earthworm, amœba, ape. State your reasons for the order you suggest.

**Self-testing exercise 7.** Compare the distribution of food in plants and animals.

#### PROBLEM 4: HOW DO LIVING THINGS OBTAIN ENERGY FROM FOOD?

**How is energy obtained from food?** **STUDY SUGGESTION.** In Problem 3 you learned how the food is distributed to the cells. In this problem, your attention will be directed toward the processes by which the cells use the food as a source of energy for body activities.

Living things must have a source of energy to do the things they do. In fact, no activity, whether by a living or a non-living thing, can be carried on without energy. If you observe the world about you, you will see that this is true.

Our machinery is run by the energy of the wind, falling water, steam, gasoline, and electricity. If the source of energy is shut off, the machinery immediately stops. Tornadoes, landslides, and earthquakes are only possible if some energy is expended. The same thing is true of living material. It needs a continuous supply of energy, or it will cease operations and die. The source of energy of all



FIG. 80. A swamp-like, coal-age forest with its dense vegetation.  
(Field Museum of Natural History.)

living materials is the food which is taken into the cells. As we have seen, the green plants have stored energy obtained from the sun, and this energy is used by the cells to obtain the energy necessary to carry on the life processes.

The body of a living thing is in many ways similar to a locomotive. A comparison of the locomotive and the body will help us to understand more clearly how energy is obtained from food. In the first place, all locomotives must have fuel. Different kinds of fuel are used, such as coal and oil. Suppose we try to determine the source of energy in the coal used to run the locomotive. Geologists tell us that coal was formed from plants. Millions of years ago certain regions of our country were covered by huge swamps in which

vegetation was very luxuriant. Many of these plants when they were old fell into the water, which prevented their decay. For hundreds of years this process continued. The weight of the top layers combined with the weight of the mud brought into the swamps by streams gradually compressed the lower layers and produced much heat. As a result of this process the plant materials gradually changed to coal. In our last problem we found that during the process of food manufacture the plants stored in the food some of the energy which they received from the sun. Since coal consists of plant materials, it therefore contains the stored energy from the sun. Thus the coal, like the food we eat, contains stored energy from the sun.

In order to drive the wheels of the locomotive, the energy of the coal must be utilized. This is accomplished by burning the coal. Burning, as you know, is a process in which oxygen unites with the material which is being burned. This is a chemical change and is accompanied by the production of heat and light. Heat and light are both forms of energy which are produced from the energy stored in the coal. The heat from the burning coal circulates through the boiler of the locomotive and changes the water in the boiler to steam. The energy necessary to run the locomotive thus comes from the stored energy in the coal. This stored energy is transformed into heat by the combination of oxygen with it, and the heat is, in turn, changed to another form of energy which drives the wheels.

Now let us return to living things. Living things use food for fuel. This food is absorbed by the cells, and is either built into new living material, or stored. It is then available to the cell as a source of energy. As in the case of coal, however, it is necessary for oxygen to combine with the cell material before the energy is released for use by the cell. This process is called *oxidation*. In this process the material used for fuel is destroyed. Oxidation takes place very slowly in the cell, and heat, but no flame, is produced. Part of the heat is

used to keep the body warm, and part is transformed into the energy which enables the muscles to move certain internal parts of the body and the parts which are used by the living thing in moving from one place to another. All living things must obtain oxygen in order to release the energy in the cell materials.

**How is oxygen obtained and distributed to the cells?**

Frogs, toads, alligators, turtles, birds, and all mammals, including man, breathe by means of lungs. The lungs are elastic sacs divided into tiny cavities. The walls of the cavities are filled with blood capillaries (Figure 81).

The oxygen from the air which enters the lungs is absorbed through the walls of the capillaries into the blood stream. Most higher ani-

mals inhale and exhale by means of ribs and muscles. For example, in man during the process of inhalation the ribs are raised by means of muscles, and at the same time the diaphragm, which is a muscular sheet separating the chest and abdomen, is pulled down. This process allows the lungs to expand. The air pressure outside of the body is thus greater than that in the lungs, and air is pushed into the lungs. When the muscles relax, the ribs return to their normal position, and the diaphragm comes up. Thus the volume of the chest cavity is decreased, and the air is forced out again. (Frogs and toads have no ribs; they swallow their air.)

The oxygen which enters the lungs must be taken up by the blood and distributed to all parts of the body. Let us see how the blood circulates. The heart may be compared

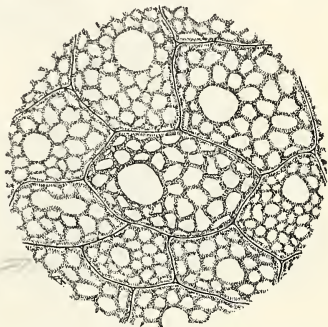


FIG. 81. How the network of capillaries in the lungs appears. The white spaces are air sacs.

to two force pumps acting side by side (Figures 82 and 83). When the blood enters the right side of the heart, it has just completed its trip through the body. It has lost much of its oxygen and contains the carbon dioxide which was produced in the cells. The blood is now in need of purification; that is, it needs to obtain a fresh supply of oxygen and to get rid of the carbon dioxide.

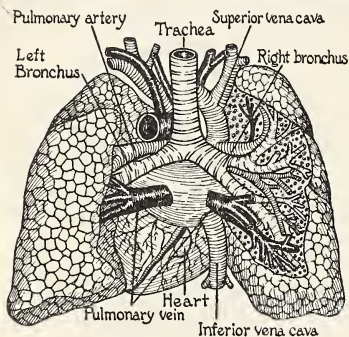


FIG. 82. The heart and the lungs. These make up the power house of man's breathing and distributing apparatus.

The blood is now in need of purification; that is, it needs to obtain a fresh supply of oxygen and to get rid of the carbon dioxide.

The walls of the right *ventricle* contain many muscles. When these contract, blood is forced into the artery which leads to the lungs (the *pulmonary artery*). This artery divides and subdivides throughout the lungs into thousands of tiny capillaries. These make it possible for the

blood to come into close contact with the air in the lungs. The oxygen diffuses through the walls of the capillaries into the blood, where part of it is dissolved and part of it is taken up by the red corpuscles. The capillaries then again unite into four large blood vessels (the *pulmonary veins*) which enter the left side of the heart.

The ventricle of the left side of the heart is very muscular, and when it contracts it forces the blood through the whole body. After the blood leaves the heart, the large artery divides into smaller arteries which supply various parts of the body with oxygen. These arteries, in turn, subdivide into capillaries so that every cell in the body may receive oxygen. The capillaries finally unite again into veins, and the blood is carried back to the right side of the heart where the same process is repeated. The time required for the blood to pass

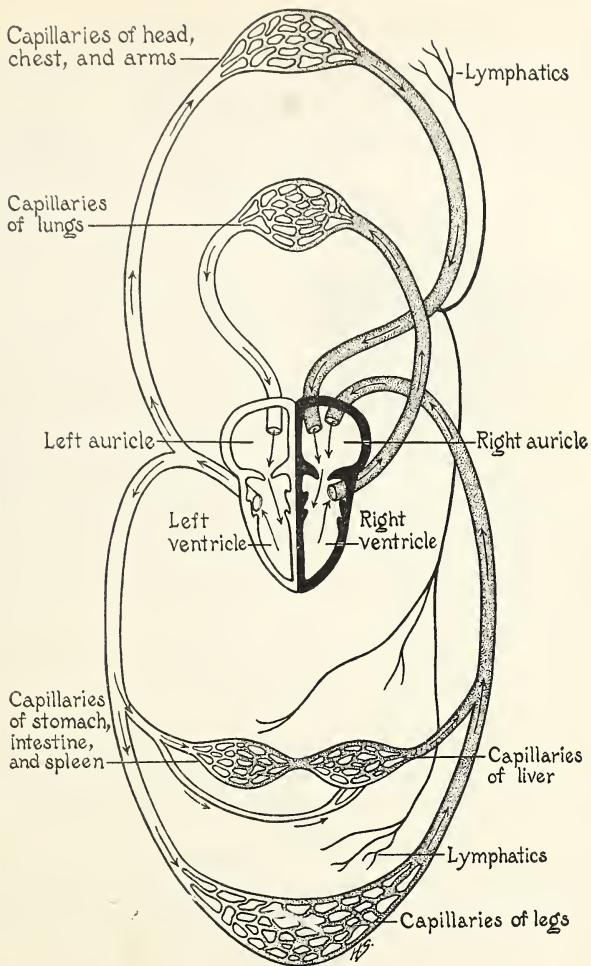


FIG. 83. The shaded part indicates the impure blood returning to the heart and lungs. The lymphatics drain the lymph from the spaces between the cells and empty it through the thoracic duct into the blood stream.

through the entire body is but half a minute. The cells are thus furnished with a constant supply of oxygen.

The quantity of oxygen required depends upon the activities of living things. If an animal is running, flying, or swimming,

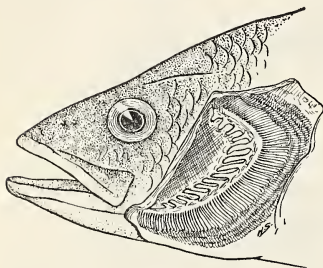


FIG. 84. Gills of a fish.

more food must be oxidized to supply the necessary quantity of energy than if the animal is resting. During activity, therefore, more oxygen must be delivered to the cells. How this is accomplished is shown by the experiment which follows.

**Experiment 19.** How does the heart regulate the amount of oxygen delivered to the

cells? (a) Place the tip of the middle finger in the hollow space just in front of the ear, or place the finger on the "pulse" in the wrist. In this position you can feel the wave produced in the blood stream when the left ventricle contracts. Count the number of waves in a minute.

(b) Repeat (a) immediately after vigorous exercise. Compare the number of beats per minute with the results obtained in (a).

(c) Answer the question of the experiment.

One-celled plants and animals absorb oxygen through the cell walls in the same manner that they absorb food. All parts of the cell wall can absorb oxygen. These plants and animals need but little energy and are so small that there is no necessity for a special method of distributing the oxygen.

Plants and animals that live in the water must, like all other living things, obtain oxygen if they are to carry on their life activities. Must they come to the surface for air, or is there air in the water? Let us see.

**Experiment 20.** Does water contain air? Fill a beaker with water and place over a flame. Heat the water slowly. Note the small bubbles which collect on the sides of the beaker and finally

rise through the water. These bubbles are air which is driven out of the water because warm water cannot dissolve as much air as cold water.

The marine worms, clams, crayfishes, lobsters, and fishes obtain oxygen from the air dissolved in water by means of gills. The gills are most perfectly developed in fish (Figure 84). They consist of comb-like fringes of delicate membranes on bony arches. The gills contain thousands of tiny capillaries. If you watch a fish in an aquarium, you will note that it constantly opens and closes its mouth. This action causes water to enter the mouth and forces it over the gills, which absorb oxygen from it. The water is then forced out the gill openings. The process of obtaining oxygen varies in the other animals mentioned in this paragraph (the marine worms, clams, crayfishes, and lobsters), but the general process is the same.

**SUGGESTED ACTIVITY.** Place a drop or two of carmine red or ordinary ink at the mouth of a quiet fish, and watch the movements of the colored liquid. Be ready to describe what you have seen.

The method of respiration which has developed in insects is called the "air-pipe system." Small openings on the side of the insect, the spiracles, permit air to enter the body (Figure 85). Connected with these spiracles are tiny tubes which have branches in every part of the body and thus form a system of air pipes. These branches follow the course of the blood vessels, and oxygen enters the blood all through the

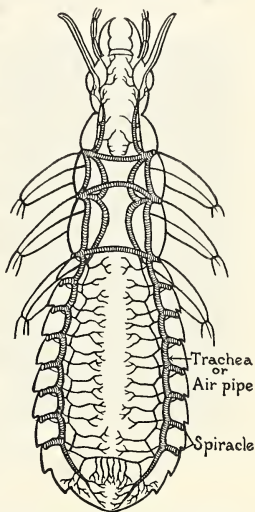


FIG. 85. The air-circulation system of a beetle.

body, the blood passing it on to the cells. Breathing is brought about by the movements of the abdomen. Although birds have lungs, they also have an air-pipe system in their bodies. Air sacs connected with the lungs are found in the abdomen and under the skin of the neck and legs. The bones are also hollow and are filled with air.

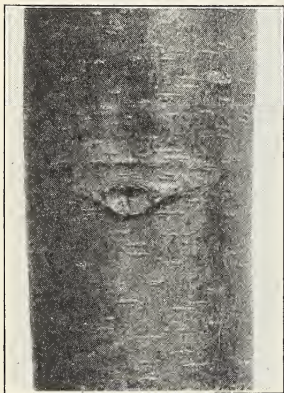


FIG. 86. Lenticels on a basswood twig. (Photo by G. D. Fuller.)

If the wind pipe of a bird is closed and the wing bone opened, the bird is able to obtain sufficient air to maintain life.

Oxygen is obtained by the higher plants mainly through the leaves and stems. In our study of photosynthesis we found that there are thousands of tiny openings, the stomata, in the leaves (see page 28). Air enters through these stomata, is dissolved in the sap, circulates through the interior of the leaf, and diffuses into other parts of the plant. The necessary oxygen is taken out of the air. Stomata are also found on the young twigs and stems of many plants, especially annuals. On the older branches the oxygen is obtained through openings in the bark, *lenticels*, in the same manner as in the stomata.

The process of obtaining energy from food is the same in all living things. The materials which are used as food are brought to the cell and become a part of living matter, or are stored in the cell. By various methods oxygen is taken into the body of the living thing and is ultimately absorbed through the cell wall. Inside the cell the oxygen combines with materials, the chemical change releasing the energy.

**What factors determine the amount of energy needed?**

\* The amount of energy necessary to carry on the life processes

and activities of living things varies with the kind of living thing. The <sup>(1)</sup>more active the living thing the greater the amount of energy needed. <sup>(2)</sup>Plants require much less energy than animals because their range of activities is limited. Some animals, like the bear, *hibernate*, that is, sleep during the cold, winter months. During this period very little energy is needed. Some animals, such as fish, are *cold-blooded*; that is, their temperature is about the same as that of the water or air in which they live. The mammals, however, are all *warm-blooded*; that is, the temperature of a given species is always about the same. During the winter <sup>(4)</sup>warm-blooded animals need more energy than cold-blooded animals in order that their temperature may be kept constant. We have already seen (page 68) that the amount of energy needed by any particular living thing also varies with the kind of activity it performs and the age of the animal. There are therefore many factors which determine the amount of energy needed by any particular living thing, and this amount varies at different times.

**SUGGESTED ACTIVITY.** If you have a clinical thermometer, take the temperature of your cat, dog, or horse. If you have no thermometer, look up the body temperature of different animals in a reference book.

**Self-testing exercise 8.** Copy the eight incomplete statements below. Fill in the blanks by using one of the following words or phrases:

Air, blood, kind of living thing, oxidation, lungs, air pipes, gills, the amount of activity, spiracles, food, oxygen, the temperature of the air, stomata, supply muscular energy, heart, the body temperature necessary for proper functioning, lenticels, supply heat.

1. The sources of energy are.....(a)..... and .....(b).....
2. The source of oxygen is the.....(a).....
3. The kind of chemical change which produces energy is called .....(a).....
4. The energy is used in animals to.....(a)..... and .....(b).....
5. The parts which take in oxygen in plants and animals are .....(a)....., .....(b)....., .....(c)....., .....(d)....., and .....(e).....

6. The oxygen is distributed in animals by.....(a)..... and .....(b).....
7. The blood is forced through the body by the.....(a).....
8. The quantity of energy required by living things depends upon .....(a)....., .....(b)....., .....(c)....., and .....(d).....

### PROBLEM 5: HOW ARE WASTE MATERIALS REMOVED FROM THE BODIES OF LIVING THINGS?

#### What kinds of waste materials are produced in living things?

In Problem 4 we compared the living organism with the locomotive and found that they were similar in two respects: first, they both need energy, and second, they obtain energy from fuels by the process of oxidation. Living things are also similar to the locomotive in another respect: In the process of oxidation waste materials are produced, and these must be carried away. In a locomotive which uses coal for energy, ashes and clinkers are always left as waste products. Certain gases, such as carbon dioxide, are also produced by the burning coal and must be removed in order to allow oxygen to enter. Similarly, waste materials are produced in cells. The materials in the cell are constantly undergoing changes which result in waste materials. Part of this waste material consists of broken-down or worn-out protoplasm.

Another part of waste material consists of carbon dioxide, which is produced when the oxygen releases the energy in cell materials. (These materials must be removed from the cells because they may poison or prevent the cells from carrying on their activities.) Wastes of this type are called *chemical wastes* because they result from the chemical processes which go on in the body. (In addition to these wastes there are also certain parts of the food which are not digested and therefore must be eliminated from the body. These wastes produce poisons if held in the body for too long a period.) *Constipation*

What methods are employed in the removal of wastes? In (a) the paramecium and the amoeba part of the waste is eliminated by means of the *contractile vacuole* (Figure 74, page 84), which bursts when full of waste material. In simple plants

and animals waste products may be given off directly through the cell walls by the process of osmosis (page 26). This same process goes on in the cells of all living things regardless of the complexity of structure. The elimination of these wastes from the body varies, however, with the structure of the living thing.

The removal of carbon dioxide from the body of man is shown by the following experiment.

*Experiment 21.* <sup>resp</sup> Where is carbon dioxide removed from the body? (a) Obtain a wide-mouthed bottle, a candle, and a glass plate. Attach a small wire



FIG. 87.

to the candle, light the candle, lower it into the glass bottle, and cover the bottle with the glass plate (Figure 87). When the candle "goes out," slide the glass plate a little to one side and remove the candle. Pour about an ounce of limewater into the bottle and shake vigorously. Observe that the limewater turns a milky color. This is a chemical test for carbon dioxide.

(b) Pour a little limewater into a bottle of ordinary air and shake it. Does it show the presence of carbon dioxide?

(c) Pour a little limewater into a bottle. Insert a glass tube in the limewater and blow through it. Is there carbon dioxide in expired air? Prove your answer.

(The carbon dioxide which is formed in the cells passes through the cell membrane into the lymph. From the lymph it passes into the blood stream and finally into the lungs (Figure 83). The carbon dioxide passes through the membrane of the lungs into the air sacs and is then removed during expiration.) This same method of carbon-dioxide removal takes place in all animals with lungs. A similar process takes place in animals equipped with gills. In some animals, like the earthworm and frog, the skin is thin and moist. The skin serves the same purpose as the membranes of the lungs; carbon dioxide passes through the skin directly to the air.

The living cells of an organism thus carry on a process of exchange of gases. The oxygen is taken from the lymph by the cell, and the carbon dioxide is taken from the cell by the lymph. This process of exchange of gases, together with the liberation of energy in the cells, is called *respiration*.



FIG. 88.

Plants also use oxygen for the production of energy. Oxygen enters the plant through the stomata in the epidermis of the leaf (page 28). The following experiment may be performed to determine if plants give off carbon dioxide:

**Experiment 22. Do plants give off carbon dioxide?** (a) Obtain a wide-mouthed bottle and pour in water to a depth of one inch. Obtain a few healthy green leaves with their stalks or *petioles* and place them in the water. Lower a small beaker of limewater into the bottle and then cover the bottle with a glass plate (Figure 88). Place in a dark place for twenty-four hours. Does the limewater show the presence of carbon dioxide?

(b) Devise a control experiment to show that the carbon dioxide did not come from the air in the bottle.

(c) Apply a thin coating of vaseline to the upper and lower surfaces of the leaves and then repeat part (a). Compare the results obtained with the results obtained in (a).

Broken-down cellular material and wastes from proteins require a rather complex method of excretion. In the higher animals these materials are carried by the blood to the liver where they are changed to another substance called *urea*. The urea then passes into the blood. Part of the urea is removed from the blood by the kidneys and excreted, and part is taken from the blood by the sweat glands (Figure 89) and poured on the skin. Other animals have definite methods of removing this type of waste, depending upon their structure.

In all methods of excretion the blood serves as a carrier of the waste materials from the cells to the parts of the body which remove these materials. You remember also that the blood carries food and oxygen to the cells. The blood therefore serves as a medium for the transportation of materials needed by the cells and the waste products which they produce. The exchange of materials in the cells is brought about by the process of osmosis.

### How is proper elimination of wastes secured?

The proper elimination of wastes in the body is one of the most important processes of life. Some scientists believe that it is the accumulation of wastes in the

cell which causes fatigue. This has not been proved, but it is certain that in some way the accumulation of wastes interferes with the performance of the body activities. Certain suggestions for helping the body get rid of wastes have been made by physicians.

- (1) Plenty of exercise causes the excretion of an abundant supply of perspiration, which helps eliminate urea. This should be followed by a bath to wash away the wastes and to prevent the pores of the sweat glands from clogging.
- (2) Plenty of water will help the kidneys in their work by supplying abundant material for dissolving wastes.
- (3) There are also always some undigested food materials in the intestines. If these are allowed to accumulate, poisonous substances manufactured by the bacteria which live there will have a bad effect upon the body. Regular evacuation of the

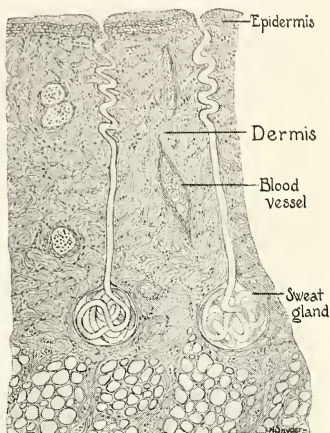


FIG. 89. A highly-magnified, section view of the skin.

large intestine is therefore necessary to prevent this from happening. The suggestions given on the preceding page will enable you to help the organs of the excretory system in carrying on their work.

**Self-testing exercise 9.** List the various kinds of wastes produced in living things: Explain how each type of waste is removed from the body.

#### ADDITIONAL EXERCISES

✓1. Does one need as much food in warm weather as in cold weather? Explain.

✓2. Write a paragraph showing how osmosis is of value to living things.

3. Why should one not exercise vigorously after eating?

4. Some trees are very much larger than the largest animal. Why do they not need a special mechanism, such as the lungs which higher animals possess, to provide them with a supply of oxygen?

✓5. Why does one tire more easily at high altitudes than at low altitudes?

6. What are some of the symptoms which indicate that one's digestion is not being properly carried on?

✓7. Why do growing children need more food in proportion to their weight than adults need?

8. Compare the burning of a material in air with the burning which takes place in the body.

✓9. Why does one become warm during vigorous exercise?

10. Write a set of directions which intelligent persons should follow in the selection of food.

11. Plan a desirable menu for yourself for a week, using such information as you have obtained in this unit and any additional information relating to dietary standards.

12. Carry out experiments to show the percentage of water and minerals contained in some of your common foodstuffs.

## UNIT III

### HOW DO LIVING THINGS GROW?

#### PRELIMINARY EXERCISES

1. Make a list of ten changes which you have observed in plants as they grow, thus:

(a) A lily bulb develops roots, a stem, and leaves.

(b) Each year new shoots appear on our maple tree.

(Add eight more.)

2. Animals show many changes as they grow. State ten changes which you have observed, thus:

(a) A young mouse develops hair on its body.

(b) A butterfly egg changes into a caterpillar.

(Add eight more.)

3. Here are the names of nine different animals: mouse, elephant, horse, whale, pig, rabbit, cat, pigeon, and alligator. These animals require different lengths of time to grow from infants to "grown-ups." Write the names of these animals in the order of the length of time that you think it takes for them to "grow up," placing first the one which requires the longest time.

4. Write the names of the seeds or sources in a column in your notebook, and to the right of each give the name of the plant which develops from it.

*Seed or Source.* Tuber, grain, acorn, spore, bulb, nut.

*Plant.* Wheat, oak tree, lily, potato, hickory tree, bacterium.

5. Give five statements which show that it is important for man to understand how living things grow, thus:

(a) If the farmer knows how his crops grow, he can fertilize his soil and cultivate the crops to make them grow better.

(Add five more.)

6. Write in a column the names of the following adult, or full-grown, animals, and opposite each write the name by which we call the animal when it is very young: bear, cat, cow, chicken, horse, sheep, dog, deer, duck, goose, and pigeon.

7. What do you mean when you say "I am growing"?

8. There are given below fourteen statements. Some are correct; others are wrong. You are to judge. Write the numbers from 1 to 14 in a column in your notebook. If a statement is correct, place a "C" to the right of its number; if it is wrong, write a "W," and then rewrite the sentence to make a correct statement.

1. Trees grow at the same rate at all seasons of the year.
  2. Organisms need food to grow larger.
  3. Living things grow larger as long as they live.
  4. The roots of plants grow larger and branch at the same time that their stems and branches increase in size.
  5. Tadpoles grow into frogs more quickly if they have an abundant food supply.
  6. The old branches of a tree are lifted higher and higher from the ground as the tree grows taller.
  7. Some non-living things grow in size.
  8. The young rabbit begins its growth very soon after it is born.
  9. Some parts of your body grow more rapidly than other parts.
  10. All of the parts which now make up your body were present when you were born.
  11. Most living things develop from a seed or egg.
  12. A butterfly develops from a caterpillar.
  13. Growth in size of plants and animals is primarily the result of cell division.
  14. It requires several years for a grain of corn to grow into a large corn plant.
9. List five kinds of materials necessary for your growth.
10. List three conditions (not materials) essential to the normal growth of boys and girls.

### THE STORY OF UNIT III

You were once a small baby. How big were you when you were born? How much heavier and taller are you now than you were at birth? The average weight of new-born Canadian babies is about eight pounds, and their average length (or height) is about twenty inches. At the age of

fourteen years most boys and girls weigh slightly over one hundred pounds and are from sixty to sixty-six inches tall. All of us grow. How much have you grown since you were born?

Other living things also grow. You have seen many cases of growth. A small puppy is a big dog a year after it is born. The grain of corn put into the ground in May becomes a corn plant a foot high in June and several feet high in August. The small chick which hatches from the egg in spring is a large hen or rooster in a few months. The baby which weighs only eight pounds at birth may grow into a young man weighing over 150 pounds. An acorn grows into a giant oak tree. Even the very smallest plant or animal, composed of only one cell, increases in size.

We can readily see that plants and animals grow, but how they grow is not so easy to observe. A grain of wheat develops roots which grow downward into the soil and stems which grow upward. New material is added to growing things, or they could not become larger. Of course, the bean plant is more than an enlarged bean seed. Certain changes must take place when growth occurs, producing materials different from those which the living things take into their bodies as food. But how and where within the living thing is this new material formed? That is a puzzling problem which we shall try to solve in this unit.

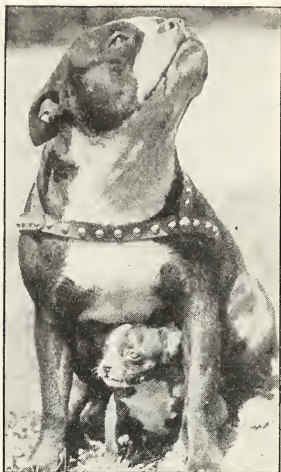


FIG. 90. This little pup weighs only one pound, two ounces. Its body will change and add new materials until it grows into an adult dog of many pounds weight. (Underwood and Underwood photo.)

Perhaps you have observed that some living things undergo very marked changes as they increase in age. Not only do they develop new parts, but they seem almost to change into

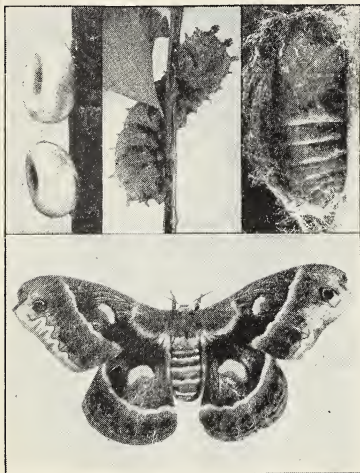


FIG. 91. The Cecropia moth lays tiny white eggs, shown here highly magnified. From the egg develops the worm-like larva, which spins for itself a cocoon, here partly torn away to show the pupa. In this cocoon development continues until finally the beautiful moth appears. (Geo. T. Hillman photos.)

new creatures. A bean seed or a lily bulb put into warm, moist soil begins to grow. Soon the seed-leaves of the bean and the blade-like tip of the lily appear above the soil. Growth continues; after a time flowers and seeds develop, and when the plant is pulled from the soil, we find a network of roots. A certain creature which begins life as an egg soon becomes a larva, then a pupa, and finally comes out of its cocoon as a beautiful moth (Figure 91). This is another illustration of how organisms change with age. These are only two of the many kinds of organisms which under-

go through marked changes as they grow from the seed or egg to maturity. Nature shows us changes of this kind on every hand. But how does the seed grow into the plant? What are the different kinds of changes which living things undergo as they grow?

You have probably noticed that some plants and animals do not grow normally, while others do. Some never develop into healthy organisms. For example, two grains of corn

are planted in a field. One grows into a fine plant bearing two ears of corn; the other becomes only a scrubby plant not bearing a single ear. Sometimes we notice that plants and animals are healthy and grow normally for a time, and then something happens to them which prevents them from attaining their normal development. Even among children and full-grown persons we see some who have failed to develop normally, although apparently they have had good care and plenty of good food. It seems that the process of growth is regulated in some way. How can this be true?



FIG. 92. These hogs were of the same age and same breed. One grew to normal size; the other failed to grow. This unit will help you understand why.

As you think about growth and its meaning, you see that you are already acquainted with this wonderful activity of living things. Perhaps you have wondered if it is of any importance for us to know how growth takes place. The farmer thinks it is. He spends much of his time getting and keeping the soil in such condition that he can produce good crops. He feeds and cares for his animals in order that they may grow large and healthy. The gardener who has some knowledge of plants and plant growth is more successful in starting young plants and producing from them beautiful flowers and fine vegetables than is the person who is ignorant about plant growth. In Unit VII you will consider how man uses his knowledge of growth in producing better plants and animals for food. The doctor and the nurse also think it is important to know about growth so that they may help babies grow into strong men and women. What does your mother need to know about your growth? What do you think you ought to know about growth?

### PROBLEM 1: HOW IS GROWTH RELATED TO THE CELL STRUCTURE OF ORGANISMS?

**STUDY SUGGESTION.** In this problem you will come to understand the process of growth in simple organisms. Then you will be able to understand better, in Problem 2, the growth of the complex plants and animals.

Ordinarily you might think that things grow larger by adding material to the outside just as a snowball, rolled along in wet snow, adds layer upon layer of snow. Non-living things do grow this way. You may recall how a hailstone in passing through alternate layers of moist, warm air and cold air grows larger by adding a layer of ice each time it is carried through a layer of cold air. Perhaps you have seen crystals of various chemical compounds grow when the water is evaporated from solutions of the compound.

**Experiment 23. How do crystals grow?** Obtain crystals of copper sulphate, sodium hyposulphate ("hypo"), alum, or table salt. Select one of these substances, powder some of it, and dissolve it in half a glass of warm water by stirring. Add enough powdered crystals so that after vigorous stirring there are some crystals left undissolved at the bottom of the glass. Allow it to settle for fifteen minutes, and then pour most of the clear liquid above the undissolved crystals into a clean glass. Now, by means of a thread, suspend a crystal of the substance in the clear solution. Set the glass in a quiet place for a few days and observe what happens. Does the crystal grow? How?

The kind of growth which you observe in the experiment is called *accretion*. The growth takes place by adding more of the same material to the outside of the original substance.

Does growth in living things take place by accretion? Can you explain the growth of a grain of corn into a corn plant by saying that the grain of corn adds more material on the outside and thus becomes a corn plant? Surely a pig does not become larger by accretion of more pig. Growth in living things is unlike growth by accretion.

You recall from Units I and II that all living things take food, and that they are composed of cells. They do add foods to their bodies, but these foods are not added without themselves being changed. The green plant, you recall, uses carbon dioxide, water, and minerals to manufacture foods. Through chemical change it is able to make these raw materials over into such substances as carbohydrates, fats, and proteins. These new substances, together with minerals, are, in turn, made into roots, stems, leaves, bark, and other parts of the plant. Similarly, a

cow may eat green grass and drink clear water and then change these into milk, hair, skin, bones, and beefsteak. These wonderful chemical changes and the cell structure of all living things give us a clue to our problem about the nature of growth.

The elements which make up food substances and the water which is absorbed are, as you have learned, made into a new substance, protoplasm. This process, called *assimilation*, changes non-living materials into living substance. How this change is brought about is not known by scientists. For years biologists have been trying to produce living materials by combining the raw materials from which protoplasm is made. Until this is accomplished, we shall probably not know how the cell is able to manufacture living material from non-living material. At present, new protoplasm can be manufactured only by old protoplasm.

As the amount of protoplasm increases, the cell becomes larger. When a certain stage is reached, the cell divides into two cells by a process called *division* (Figure 93). Note that both the nucleus and cytoplasm divide, one-half going to make up each of the new cells. These new cells take in food, manufacture protoplasm, and increase in size. Thus

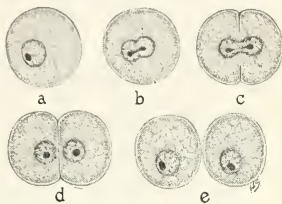
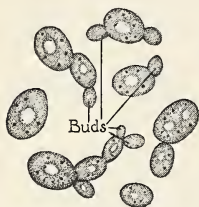


FIG. 93. Stages in cell division.

all one-celled organisms begin life as small cells and grow larger by changing non-living materials into new living protoplasm, or organic material.



In some simple organisms, like the yeast, the cell does not divide into two cells of equal size, such as are shown in Figure 93, but it develops one or more *buds* (Figure 94). In time these buds get larger as more protoplasm is produced by the mother cell. Let us examine some yeast plants.

FIG. 94. Yeast plants. **Experiment 24. How does the yeast plant grow?** Examine some yeast plants which have been placed in a ten-per-cent solution of sugar or syrup for several hours and kept warm. Look at Figure 94 and then examine the yeast under the microscope. Do you see the buds on some of the yeast cells? Can you find cases where these buds are very small, and other cases where the buds are larger? After a time, these buds usually separate from the mother cells, forming new yeast plants.

Examination of various kinds of simple plants and animals shows that the new cells formed by division do not always separate from each other. Sometimes they adhere to each other in the form of spherical colonies, narrow *filaments* or threads, plates, or sheets.

**Experiment 25. How do similar cells form colonies and filaments?** (a) Obtain some of the green material, called *Pleurococcus*, which grows on the bark of trees, usually on the north side. Scrape a little of this material off the bark, place it on a slide, and mount in a drop of water. Examine the material with the microscope, observing that some of the little cells are in colonies of two or more (Figure 95). Each of the cells divides when the cell increases to a certain size, and sometimes the new cells stick



FIG. 95. *Pleurococcus* cells, (a) single, and (b) in colonies.

together, forming the colony. In the colony of *Pleurococcus* cells each cell is an independent plant and has the same structure as the other cells of the colony.

(b) Examine some *Spirogyra* under the microscope. Note the long cells as shown in Figure 96. Observe how the cells are arranged in a filament formed by the division of a single original cell. If *Nostoc*, *Oscillatoria*, *Ulothrix*, *Cedogonium*, and such brown algæ as *Ectocarpus* and *Fucus* (rock-weed) are available, examine them for their interesting cell arrangements.

As we examine other simple forms of plant and animal life, it may be seen that in some forms all of the cells produced by division are not exactly alike. For example, in the plant

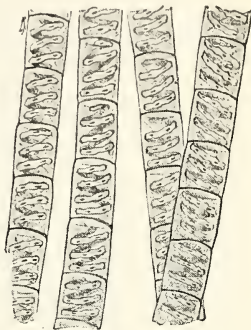


FIG. 96. *Spirogyra*.



FIG. 97. *Ulothrix*.

called *Ulothrix*, shown in Figure 97, one of the cells in the filament is longer and narrower than the others and has a *holdfast* at the base by which it attaches itself to objects. Thus the filament may be made up of two kinds of cells, both produced from the original cell by division. Among the simpler animals we may take as an example the hydra, which you have previously met (see page 85). The hydra develops from a single cell which divides into two, four, eight, sixteen, and more cells. As the cells continue to increase in number, some of them are unlike the original cell. Some of the cells are used to hold the hydra to its support, some appear as tentacles, some are used to sting, and some are used to digest food (see Figure 75). In these few examples

of the simplest forms of plant and animal life you see another phase of growth, that is, the development of new cells for

special purposes. This is called *differentiation*. The new cells are not independent organisms like the one-celled amoeba, the yeast, and the Pleurococcus; all of them together form the new organism with its various parts.

The preceding paragraphs and experiments of this problem furnish you with the fundamental explanation of how living things grow. Every organism begins life as a single cell. This cell assimilates food, builds protoplasm, and increases in size. If the organism is one-celled, it divides into two cells, each of which is like the parent cell. If the organism is many-celled, the division likewise continues as new protoplasm is produced. However, except in some of the simplest plants and animals, the new cells are not all of the same kind, and they hold together to make up the living thing. In the higher plants and animals the new cells are of many different kinds, as you learned in Unit II (see page 73).

In general, then, we may say that growth consists of (1) the assimilation of non-living substances and the production of protoplasm, (2) the increase in the size of the cell or cells, (3) the increase in the number of cells, and (4) the development, in higher organisms, of different kinds of cells which serve special purposes.

**Self-testing exercise 1.** Copy the paragraph below. As you copy it, fill in the blanks with the proper words. Use only one word for each blank.

Living things, unlike non-living things, do not grow by the process of accretion, but by the process of assimilation. In assimilation non-living materials are changed into the living stuff, called protoplasm, inside the cells of the organism. When the cells reach a certain size, they divide, producing two individuals. In this process both the nucleus and cytoplasm are separated into two parts. In the higher organisms, which are composed of many cells, growth consists not only of increase in the number of cells, but also in the production of new kinds of cells. This phase of growth is known as differentiation of cells and results in the formation of different parts in the organism.

## PROBLEM 2: HOW DO HIGHER PLANTS GROW?

**STUDY SUGGESTION.** In this problem you will consider a few of the higher plants as examples of growth and try to understand how and where some of the changes that were mentioned in Problem 1 take place.

**How does the seed grow into a young plant?** Most of our common plants in the garden and field grow from seeds. We shall, therefore, begin our study of this problem by examining the seeds of two plants with which we are all familiar. Let us see what the parts of these seeds are from which the plant grows. We shall examine the bean and the corn. These are large, and it will be possible to find the parts. Then, too, the bean and corn represent two important classes of seed plants.

**Experiment 26.** What are the important parts of the bean seed and the corn grain? (a) Obtain a dry kidney or lima bean and one that has been soaked for a day. Examine these and find the various parts that are shown in Figure 98. Look up the meaning of these new words in the glossary. Also read the paragraph following this experiment.

(b) Examine a dry grain of corn and one that has been soaked. Refer to Figure 99 and locate the various parts.

(c) How does soaking the seeds in water change the appearance of the seeds?

When the *seed coat* of the bean is slipped off, the seed is seen to consist of two halves, called *cotyledons*. Packed away in the corner of one half is a small body which consists of two easily seen parts. If you examine it closely with the naked

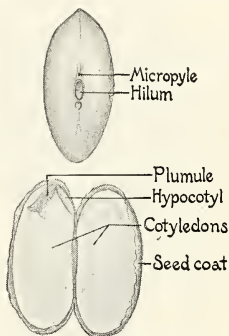


FIG. 98. The *hilum* is the point at which the bean is attached to the pod. The *micropyle* is a tiny hole, whose use you will learn later in this unit.

eye, or better still with a small hand lens, you can easily make out the part which grows into the stem and leaves and the part which develops into the root.

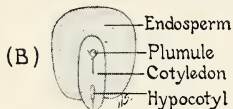
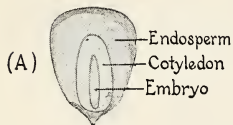


FIG. 99. Parts of the corn seed. (A) Outside view; (B) seed coat removed. The *plumule*, cotyledon, and *hypocotyl* make up the embryo.

The two halves of the seed consist of food which has been stored there by the plant. This food furnishes the material necessary for growth until the young plant has developed to the point where it can manufacture its own food. The two halves of the seed and the parts which grow into the stem and roots make up what is called the *embryo*.

The embryo is really just a miniature plant. Figures 98 and 99 show the names of the different parts of seeds. It will be necessary for you

to know the names of these parts in order to read the discussion which follows.

The corn grain has a somewhat different structure from the bean seed. Figure 100 shows that the embryo is but a small part of the seed. The major part of the grain of corn consists of the starchy part or *endosperm*. This endosperm supplies the food material for the growing plant. It thus has the same use to the plant as the cotyledons of the bean seed. The corn embryo differs from the bean embryo in that it has but one cotyledon. As you will learn in Unit VI, the difference in the number of cotyledons is one of the bases used to classify plants into different groups. Those with one cotyledon are called *monocotyledons*; those with two cotyledons are called *dicotyledons*. Now let us see what happens during the process of growth.

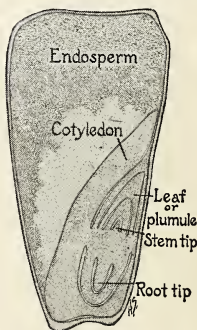


FIG. 100. Longitudinal view of a corn grain.

**Experiment 27. How do bean seeds and corn grains develop?**

(a) Obtain lima or kidney beans which have been soaked for a day and then planted in moist sawdust or soil and allowed to develop for two days, for five days, for eight days, for ten days, for twelve days, and for two weeks. Observe them as you remove them from the soil, noting the position of the various parts with respect to the surface of the soil and to each other. Spread the different samples before you, and with the help of Figures 101 and 102 observe what has taken place. Answer the following questions:

1. What part of the seed first breaks through the seed coat—the part that develops into a root (the *radicle*) or the part that develops into the stem? How long after planting does this occur?

2. In which direction does the radicle grow? The radicle becomes the *primary root*; the branches from the primary root are *secondary roots*. How long after planting does the radicle branch, forming secondary roots?

3. How are the cotyledons and *plumule* brought above the ground? What changes occur in the cotyledons and plumule as the plant develops?

(b) Repeat part (a), using sweet corn or field corn in the different stages of development. Try to answer the following five questions:

1. What part of the grain first breaks through the seed coat?

2. What part of the seedling first shows itself above the soil?

3. Is the cotyledon lifted out of the soil by the *hypocotyl* as in the case of the growing bean seed?

4. How do the first leaves differ in appearance from the leaves of the bean?

5. What happens to the endosperm as the plant grows larger?

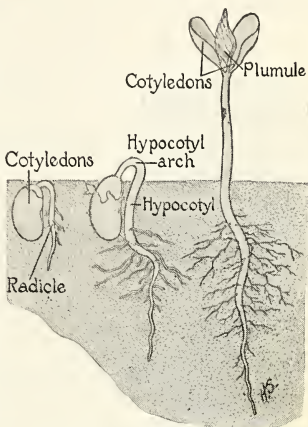


FIG. 101. Early stages in the germination of the bean seed.

**SUGGESTED ACTIVITY.** Soak different kinds of seeds and grains in water including clover, radish, turnip, mustard, peas, oats, squash, pumpkin, sunflower, watermelon, peanut, barley, and rye. Let them soak for 24 hours; then examine each seed and try to find the parts

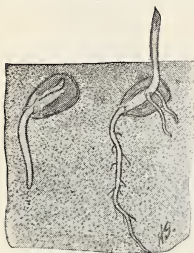


FIG. 102. Stages in the germination of a corn grain.

shown in Figures 98 and 99. Classify the seeds according to whether they belong to the same group as the corn or the same group as the bean.

**Self-testing exercise 2.** Examine Figures 101 and 102 and, recalling your experiment, state the principal steps which take place as the seed or grain develops, thus:

(A) The bean develops as follows:

(1) The seed coat splits open.

(2) The radicle goes downward in the soil.

(Add as many more statements as you can.)

(B) The corn (etc.)

The first step in the growth of the seed is the swelling of the seed caused by taking in water either through the *micropyle* or by osmosis through the cells of the seed coat. The protoplasm of the embryo becomes diluted (thinner) by the addition of water, and the living cell then begins to respire. This respiration is the second step in *germination*, or the change from a seed to a young plant.

**Experiment 28.** How can we show that seeds respire? (a) Obtain four bottles of the same size fitted with rubber stoppers. Into each of two of the bottles pour a small handful of wheat or corn grains which have been soaked for 24 hours. Stopper the other two bottles and set all aside for two or three days.

(b) Lower a small, burning candle into one of the bottles with seeds in it. Note how well the candle burns. Repeat, using one of the bottles without seeds. Explain the difference in results.

(c) Turn the second bottle containing seeds mouth-downward; quickly remove the stopper to let the seeds fall out, and immediately re-stopper and invert. Now add 20 cubic centimeters of limewater and shake. Result? Repeat the limewater test on the air in the second bottle which did not contain seeds.

(d) What do you conclude from this experiment?

**SUGGESTED ACTIVITY.** Fill a small wide-mouthed bottle with dried peas. Pour in water and then cork the bottle. Wire the cork in place as firmly as possible. What happens? What is your explanation?

The fact that germinating seeds take in oxygen and produce carbon dioxide shows that the living cell begins to respire early in the process of germination. The respiration produces heat which keeps the seeds warm, as one may easily show by taking the temperature of germinating seeds. Respiration also produces the necessary energy to carry on the growth process.

**Experiment 29. Do germinating seeds give off heat?** Devise an experiment which will prove that germinating seeds are warmer than seeds which are not germinating.

The third step in the growth of the seed is the digestion of the foods which are stored in the seeds. Chemical tests show that practically all seeds, as well as bulbs and tubers, from which higher plants grow, contain starch, protein, and fat or oils. These food substances are insoluble in water and cannot be used directly as foods by the embryo. In the process of digestion the embryo produces enzymes, which you recall from Unit II. These, then, change the starch, proteins, and fats or oils in the seed into soluble materials. Experiment 17, page 78, showed you that diastase, one of the enzymes, changes insoluble starch into soluble sugar. Similarly, other enzymes change proteins and fats into such forms that they can be absorbed.

The fourth step in the germination of the seed is the transfer of the digested foods to the growing points of the plumule and radicle. This takes place mainly by osmosis from one cell to another until the food reaches the growing points.

The fifth step is the assimilation of the soluble food materials in the growing cells. These materials are changed into new protoplasm, and the cells of the embryo enlarge and divide into more and more cells until the seed coats are broken open by the pressure of the growing cells. These five

changes are much the same in all seeds, but from here on it becomes necessary to consider different seeds for further changes.

In the bean the radicle is first to come out of the seed coat. As it receives food from the cotyledon, it increases in length



FIG. 103. Later stages in the growth of the bean plant.

by division of the cells near its lower end and also forms epidermal cells on the sides. Thus it becomes the primary root. Some of these epidermal cells grow long extensions at the side, forming root hairs, as you learned in Unit I. The primary root branches, forming secondary roots, each of which has growing cells near its end. Thus the seedling develops a root system. While the root system is developing, the hypocotyl grows at the opposite end, forming an arch and lifting the cotyledons out of the ground, usually minus their seed coats. The plumule slowly develops into leaves with many cells. The cotyledons continue to furnish food to the plumule. At the same time

they develop cells with chloroplasts which for a short time carry on photosynthesis and thus manufacture food for the seedling plant. But as the leaves develop, the work of the cotyledons becomes completed, and they shrink and practically disappear (Figure 103). By this time the leaf and

root systems are developed far enough to manufacture the necessary food for further growth. The seedling is now a young plant.

In seeds like the corn the primary root is first to emerge from the seed coat. Soon branches called lateral roots appear at the sides. The plumule also receives digested food from the endosperm, and by division of cells it produces the young shoot which contains the leaves enclosed in the *leaf sheath*. As the leaves go on growing, the sheath is broken open, and the first leaf or blade appears underground. At the base of the shoot roots develop and extend outward in all directions. As growth continues, other leaves develop and other roots grow from the stem. These roots take the place of the primary root system which soon dies. During all this time the endosperm and cotyledon remain in the soil, the cotyledon serving to transfer digested food from the endosperm to the growing parts. The leaves continue to push their way upward through the soil and emerge above ground. Once in the sunlight, the leaves develop chlorophyll, become green, and begin to manufacture food. By the time the stored food of the endosperm is exhausted, the plant is able to manufacture its needed food supply. Germination is now complete, and the seedling has become an independent plant.

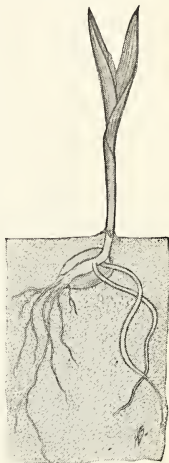


FIG. 104. Later growth of corn plant.

Thus you have traced, in very brief form, the story of the growth of certain higher plants from the seed to the young plant. There are many more details to the complete story. These you may some day learn in advanced biology or botany, or by yourself. Nor have you completed the story of the growth of the plant, for you have not considered the

production of flowers, fruits, and seeds. This part of the story we shall leave until the next unit.

**SUGGESTED ACTIVITY.** You can see for yourself how a root grows in length by doing the following experiment: Obtain a bean seed which has developed a root about one-half inch in length. Moisten a piece of thread with India ink and make marks at regular intervals along the root. Place the seed in damp sawdust. Remove it occasionally and observe if all parts of the root grow equally. What are your conclusions?

**SUGGESTED ACTIVITY.** Test different kinds of seeds to determine their food content. Refer to Experiment 11, page 34, and Experiment 16, page 76, for the test for starch and sugar. To test for protein, grind the seed into small particles. Pour the particles in a test tube and add a small amount of nitric acid. Heat to boiling and then add ammonium hydroxide. If protein is present, the material will change to a deep orange color. To test for oil, break the seeds in small pieces and place them on a piece of brown paper. Heat the paper and seeds in an oven. The presence of oil is shown by a grease spot which can be detected if the paper is held to the light.

Arrange your results in a table to show the composition of different seeds.

**Self-testing exercise 3.** Answer each of the following questions in one or a few complete sentences:

1. How do you know that germinating seeds respire?
2. How are the foods in seeds digested during germination?
3. What is the function of the endosperm of a corn grain?
4. From what part of a bean seed do the first leaves develop?
5. How does the shoot of a seedling originate?
6. What is the difference between the primary roots and the secondary roots?

**How does the young plant continue its growth?** The complete story of the growth of the young plant into an adult plant is complex, and belongs to the study of botany. Only a few of the principal stages will be considered here. We can understand these stages better if we first examine the growing twig, or *shoot*, of a tree, for this will show clearly the principal parts that illustrate growth.

**Experiment 30.** What are the principal parts of a shoot?

Obtain some young shoots from trees such as the apple, pear, horse-chestnut, buckeye, or poplar. Find the bud that is at the tip of the shoot. Open it carefully and observe the young overlapping leaves. This bud, called the *terminal bud*, is a *leaf bud*; it develops during the following spring into a new branch or shoot and leaves. Note, too, the *lateral buds* along the side of the twig. These may be either leaf buds or *flower buds*. Open them and observe their structure. Just below the lateral buds you will see moon-shaped scars left where the leaves fell off the twig.

Now run down the twig from the terminal bud until you come to a ring of scars all the way around the shoot. You will find on the way down the shoot several enlargements or *nodes*, where the leaves develop, and you will notice the sections between the nodes, called *internodes*. Be sure that you do not confuse these nodes with the ring of scars which you are trying to locate. The ring of scars was caused when the terminal bud scales fell off during the previous spring. This ring, therefore, marks the place where the growth started the previous spring, and the distance from this ring to the end of the twig shows the growth for one year. See if you can find other rings farther down the twig or shoot, and by means of them determine the age of the shoot. Do you find any branches or shoots which are only one year old? (Refer to Figure 105 if you need help in finding the different parts of the shoot that you are examining.)

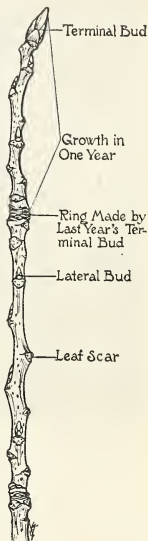


FIG. 105. Parts of a shoot.

As growth continues to take place, the young stem becomes longer by further division of cells at the tip and by increase in the length and number of the cells of the internodes. Meanwhile the leaves develop at the nodes. Here and there on the stem may be seen buds. Some of these, leaf buds, develop into branches; others, the flower buds, may later

become the flowers (Figure 106). At the end of the main shoot and of each branch of most plants is a terminal bud which grows by cell division as food is supplied. (Not all plants have terminal buds.) Thus you see that the stem and branches

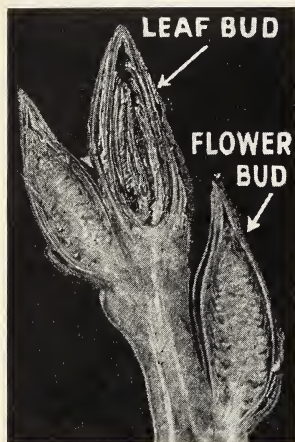


FIG. 106. Section view of buds of a balsam poplar twig. (W. C. McCalla photo.)

elongate by increase in the size and number of cells, and that leaves and flowers develop from buds on the stem by cell division and increase in size.

In plants like the corn and bean, the shoot, as you know, is produced at one end of the embryo when the growing cells differentiate. The terminal bud results from this differentiation of cells. This bud consists of a minute stem with nodes, with internodes, and with young, undeveloped leaves at the nodes, just as you have seen in the case of the tree shoot.

The leaf system of the young plants carries on photosynthesis during the daytime and sup-

plies the food for building new protoplasm at the growing points. Meanwhile the plant continues to respire, which process destroys protoplasm (see page 90). Thus two processes are taking place at the same time. The building up process is called *anabolism*; the tearing down process is known as *catabolism*. Together these two processes are called *metabolism*. Under favorable conditions the leaf system can manufacture enough food in the daytime to build more new protoplasm than is destroyed by respiration. When anabolism exceeds catabolism, growth in the size of cells and the formation of new cells usually take place.

The growth in length of stems of plants like trees, which

live more than one year, is no different from that of the shoots already described except that new internodes are added each year as the terminal buds develop. The internodes of the previous year remain the same in length. This you may know by observing that branches of trees are not raised higher above the ground as the tree grows. You can prove this by driving a nail into the bark of a tree and observing years later that the nail is just as far above ground as it was originally. The increase in length of the stem, then, takes place at the end.

**SUGGESTED ACTIVITY.** Examine the shoots of as many kinds of trees as possible and determine the average rate of growth for each kind of tree. Arrange your results in a table. Compare your results with those that were obtained by other pupils.

**SUGGESTED ACTIVITY.** Examine the shoots of several trees of the same kind. Determine the average rate of growth for each tree. Do trees of a certain kind grow at about the same rate, or do they differ in their rate of growth? If you find a certain tree whose rate of growth is markedly different from that of the other trees, try to determine the cause for the difference.

**SUGGESTED ACTIVITY.** Try to find a tree or shrub which does not have a terminal bud. Compare the shape of this plant with another plant which has a terminal bud.

Not only do plants increase in length; they increase also in diameter. We can understand how this type of growth takes place by examining the structure of stems.



FIG. 107. This twig of a white ash shows plainly the terminal and lateral buds and the leaf scars. Note how the twig is sending out new branches at the two nodes. (G.D. Fuller photo.)

**Experiment 31. What is the internal structure of the stem of dicotyledons?** (a) Examine a cross-section of the trunk of a young tree, such as ash, oak, poplar, willow, or apple. A cross-section of a limb will serve equally well. Why? Locate the *bark*, the *wood*, and the *pith*. If you use a green branch, peel off some of the bark and note the slimy surface of the *cambium* cells just under the bark. The cambium is the growing part of the stem, and the

slime is nothing more than protoplasm from the cambium cells which you ruptured by tearing off the bark.

(b) Study Figure 108; then examine the stem with a magnifying lens to observe the *annual rings*, composed of a layer of loosely arranged wood and a layer of more compact wood.

(c) If cross-sections of stems or branches of dicotyledons of one year, two years, and three years are available, examine them under

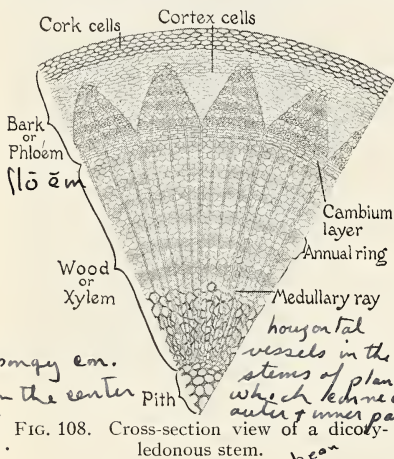


FIG. 108. Cross-section view of a dicotyledonous stem.

the microscope; locate, with the help of Figure 108, the *cork* cells, *cortex* cells, *phloem*, *cambium*, *xylem*, *pith*, and, in the two- and three-year-old sections, the *annual rings*.

The growth in diameter of dicotyledonous stems takes place in the cambium layer. This is the growing layer. As division of these cells takes place, new wood cells are added to the xylem inside the cambium, and new phloem cells are added to the bark. The food necessary for this growth is brought through the tubes of the phloem to the cambium cells from the leaves, where, as you know, it is manufactured.

The rate of growth of cambium cells depends upon the amount of food brought to the cells. In the temperate zone the

growth is most rapid in the spring. At that season food is abundant, and the cambium cells divide rapidly, forming loosely arranged wood cells. In the summer the food supply is less, and the wood formed is more compactly arranged. There is usually little or no growth in fall and winter. Thus the year's growth consists of a layer of "spring wood" of large cells and a layer of "summer wood" of smaller and more compact cells. Together these two layers make up the annual ring. Figure 109 shows a photograph of the cross-section of a tree which has over one hundred rings.

Let us now see how the stem of a monocotyledonous plant increases in diameter.

**Experiment 32.** What is the internal structure of a monocotyledonous stem? Examine a cross-section of a corn stem and note: (1) the epidermal layer, or cortex, (2) the fibrovascular bundles scattered through the stem, as shown in Figure 110, and surrounded by (3) a pithy material called *parenchyma*.

In the very young monocotyledonous stem the internal structure is much like that of dicotyledons, but as the stem

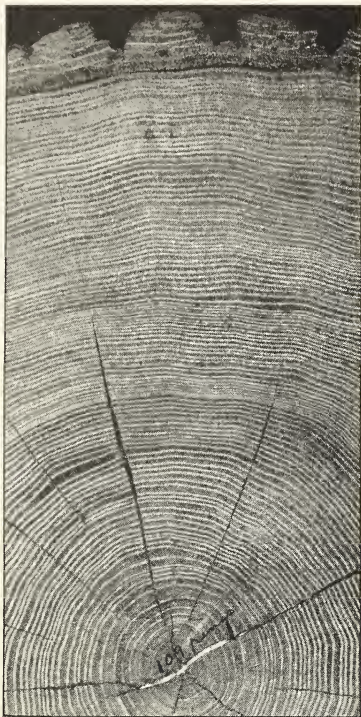


FIG. 109. Annual rings of an elm tree.  
(Field Museum photo.)

grows older, the fibrovascular bundles increase in number and become scattered throughout the pith. These bundles, unlike those of the dicotyledons, contain no cambium layer.

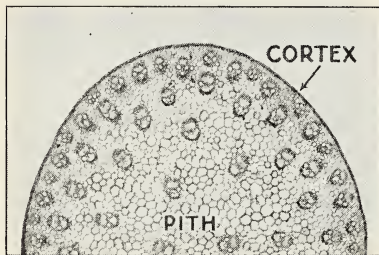


FIG. 110. Cross-section view of a corn stem (monocotyledon).

There is, therefore, no seasonal growth in diameter through formation of new wood or pith, and no annual rings appear. The increase in diameter of the young stem is caused by increase in the number of fibrovascular bundles and by increase of the size

of the cells as food brought by the *sieve tubes* in the bundle is converted by the cells into new materials. Old stems usually grow only by increase in size of the cells.

The beginnings of the root system of higher plants are, like the shoot system, present in the embryo. The very tip of the root is composed of a thimble-shaped mass of cells called the *root cap* (Figure 111), which serves to protect the growing part just above it. Some of the new cells that develop in the growing part become root-cap cells and replace cells worn away as the root is pushed through the soil; others add to the length of the root by growing in length just above the growing point; and still others make up the new growing region and go on dividing. The *taproot*, or primary root, thus increases in length. Here and there branches arise from the primary root, forming secondary roots which grow in the same way as the primary roots. At certain parts of the root the root hairs arise as outgrowths of epidermal cells.

There is one further idea about the growth of the roots of plants which you should not overlook. The primary root system which has been described is the permanent root system

of such plants as beans, beets, maple, and oak. In other plants, such as corn and wheat, the primary root system soon dies, and its place is taken by *adventitious* roots, that is, roots which grow from neither the hypocotyl nor from other roots. These adventitious roots grow out at the nodes on the stems above the primary roots. Sometimes they come from the stem above the soil and turn downward into the soil; in other cases they grow from the stem beneath the surface of the soil (Figure 104). This is the permanent or *fibrous root system* of such plants as grasses, wheat, barley, corn, and rye. The continued growth of these roots takes place at their growing points.

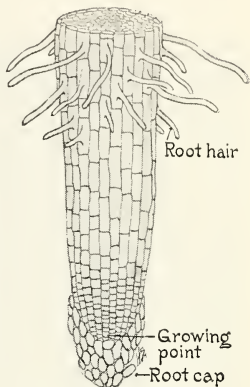


FIG. 111. Root tip.

Practically all of the seed plants develop into mature plants in somewhat the same way as has been described. Some of them, as nasturtiums, zinnias, beans, and peas, develop flowers and seeds in a single season, and the plants then die. These are called *annuals*. Others require two growing seasons to develop from seed to seed, and then die. These are known as *biennials* and include such plants as sugar beet, carrot, cabbage, and parsnip. Still other plants, like trees, shrubs, and dandelions, go on living year after year and bear flowers and seeds each year. These plants are known as *perennials*.

**SUGGESTED ACTIVITY.** Obtain full-grown pea plants, wheat, corn, and potato, and also a one- or two-year-old maple, beech, pine, peach, oak, or elm tree. Examine the exterior of the stem and root system of one of these plants to see and identify the parts. Explain the origin and development of each part of one of the plants.

**How rapidly and to what size do plants grow?** Let us now consider how rapidly and how large some plants grow. Many plants complete their growth in a single season. The amount of increase in length of stem depends upon the conditions, of course. An ordinary bean plant may grow five or six feet high in a few months. The tomato plant produces a branched stem several feet high during the spring and summer. Field grains, like oats, barley, rye, and wheat, grow about four or five feet high during a good growing season. Sunflowers and corn may reach a height of ten feet or more. A twenty-foot corn plant is not unknown. Various climbing vines extend their shoots twenty feet or more. Hop vines have been known to grow forty feet in length in one year.

In perennial plants, like the trees and shrubs, the rate of growth increases as the leaf and root systems become well established. The young pine tree, for example, is only an inch or two high at the end of the first year of growth from the seed, but during the next fifty years it may grow to be over sixty feet high. This means that its average yearly growth has been over fourteen inches. During the second fifty years, however, the rate of growth decreases to a yearly average of about four or five inches. The second century of its growth adds only about 100 inches to its height. The period of youth for the tree is its period of most rapid growth, just as it is for you.

The rate of growth in the diameter of plant stems is dependent upon the kind of plant, just as the rate of growth in length of stem is. Monocotyledons, for example, corn, cat-tails, and lilies, as a rule complete their growth in diameter of the stem in a single year. The dicotyledons, as you recall, grow year after year by cell division in the cambium layer and add annual rings. In some trees, like young poplars and young basswoods, the rings may be nearly one-half inch thick, which would mean an increase in diameter of almost one inch in a year. The rate of growth in diameter becomes less as the tree grows older.

While the stems of plants grow, the roots also develop. The length of the taproot is often much greater than the height of the stem. Thus, in alfalfa it is not unusual to find taproots from ten to twelve feet in length and side roots even longer. In regions where water is scarce, roots may go very deep. In dry regions, fibrous roots of wheat may extend to a depth of fifteen feet or more. Even the short asparagus plant grows roots eight or nine feet long, and a stubby-stemmed plant like the sugar beet sends its taproots five to seven feet into the soil. These cases are, of course, rather exceptional, but they show the possibilities of growth. Some studies of oat plants show that the total length of the root system is as much as 125 to 150 feet. One botanist states that he found roots of an oak tree that measured 450 feet over all.

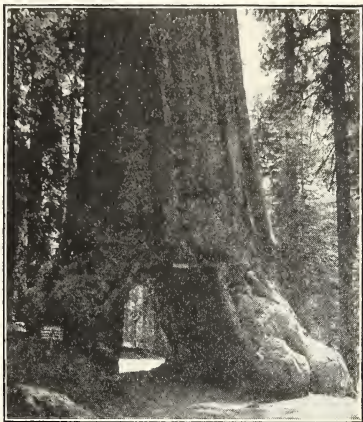


FIG. 112. This giant sequoia is 227 feet high and 26 feet through. The roadway was cut nearly 60 years ago. (W. C. Thompson © photo.)

There is no definite limit to the growth of the hardy perennials like trees and shrubs. They seem, as a rule, to grow as long as they live. The age at which they produce flowers and seeds varies with the kind of perennial. Some continue to produce flowers, fruit, and seeds every year throughout their lives. The size to which these perennials grow is naturally dependent upon the kind of plant and the conditions under which it lives. Common fruit trees, for example, do not grow as tall or as large in diameter as the trees of the forest,

such as oaks, basswoods, sycamores, pines, or the giant cedars and Douglas firs of British Columbia.

Forest trees represent the largest and oldest plants. A few facts about them will be of interest to you. Table 4 shows the approximate height and diameter of some of the largest trees. The ages to which some trees grow are indeed also interesting. The count of the annual rings and the estimate

TABLE 4. HEIGHT AND DIAMETER OF SOME LARGE FOREST TREES

| KIND OF TREE            | HEIGHT      | DIAMETER  |
|-------------------------|-------------|-----------|
| Elm.....                | 50-100 ft.  | 6-11 ft.  |
| White oak.....          | 80-100 ft.  | 3-4 ft.   |
| Burr oak.....           | 150 ft.     | 6-7 ft.   |
| Valley oak.....         | 100-125 ft. | 7-10 ft.  |
| White ash.....          | 120 ft.     | 5 ft.     |
| Eucalyptus.....         | 480 ft.     | 81 ft.    |
| Sequoia (Big Tree)..... | 200-330 ft. | 20-28 ft. |

of age from rate of growth give approximate figures like these: fruit trees, 60 to 70 years; elm, 300 years; cypress, 800 years; oak, 1500 years; cedar, 2000 years; yew, 3000 years; sequoia, 4000 years. These figures may be too high for some trees, but one scientist found by accurately counting the annual rings of eighty-three sequoia trees that seventy-nine were over 2000 years old, and four were over 3000 years old. Near Oaxaca, Mexico, is a great cypress tree that is estimated to be not less than 5000 years old.

**SUGGESTED ACTIVITY.** Obtain branches about one or two inches in diameter of as many different kinds of trees as possible. Measure the diameter of the branch as accurately as possible (you may be able to borrow a pair of calipers from the physics laboratory) and count the number of rings. Calculate the average rate of growth per year of each tree. Arrange your results in a table and compare them with those obtained by others in the class.

**Self-testing exercise 4.** State in a series of sentences the big ideas (from five to ten) which you have learned in this problem. These ideas should be expressed in terms of the cell nature of growth, and, taken together, they should constitute a good answer to Problem 2.

### PROBLEM 3: HOW DO HIGHER ANIMALS GROW FROM EGG TO ADULT?

**STUDY SUGGESTION.** The growth of the higher animals varies so greatly for different animals that it is possible to include here only a few kinds of animals which represent some of the more common types of growth or development.

The higher animals begin their lives as eggs. In some kinds of animals the egg is formed inside the mother animal, is inclosed in a shell or membrane, and, when fully formed, is discharged from the mother's body. We say the mother "lays her eggs," as is true in the case of insects, frogs, toads, turtles, birds, and some fishes. The development of the egg then takes place outside the mother's body. In the case of other animals, like the rabbit, opossum, kan-

garoo, mole, bat, dog, bear, wolf, cat, walrus, squirrel, beaver, monkey, and man, the egg is also formed inside the mother's body. Of course, it is not inclosed in a hard shell like that of the chicken, or a soft shell like that of the turtle. It develops in the mother's body until the young animal is nearly or entirely ready to take its own food. The young animal is then born. The egg-laying animals are called *oviparous*, which means "bringing forth eggs." The members of the other group are said to be *viviparous*, which means "bringing forth living young."

There are many striking changes in the development of certain animals from the egg to the adult stage. A frog, for example, passes through many stages from the egg to the full-grown frog. Examine Figure 113, which shows several stages in the development of a frog's egg. Note that the egg first divides into two parts, then into four, and so on, and

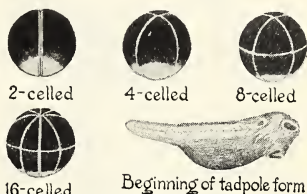


FIG. 113. First stages in the growth of the frog.

later the small tadpole, or polliwog, develops. Still later, the tadpole slowly changes into the frog.

The time required for these changes varies with the kind of frog and the kind of season. The eggs are usually laid in fresh water ponds by the mother frog in March or April.

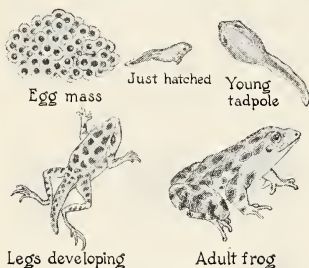


FIG. 114. Life history of the frog.

Hundreds of eggs are laid at one time surrounded by a grayish, jelly-like mass. Within a few days (in warm weather) each small egg *segments*, that is, divides into many cells, and the mass of new cells becomes an oblong body shaped like a tadpole. This tadpole separates itself from the jelly-like mass which surrounds it and attaches itself to

a twig, weed, or other solid body. At the time of hatching, gills appear on the outside of the body. Later, gills somewhat like those of a fish are developed. Then the tadpole develops hind legs, and, in time, front legs also appear from beneath the skin where they have developed.

The next stage is the slow change from the tadpole to the frog. In the leopard frog this change is usually complete by August. In the case of the bullfrog and the green frog the tadpoles grow during the summer and then spend the winter in the mud at the bottom of the pond or stream. The following spring the change from tadpole to frog is completed. The gills are absorbed and lungs are developed. The long tail is absorbed, and the legs, especially the front legs, now increase in size.

This interesting series of changes is called *metamorphosis*, which means change of form. Many animals, such as toads, newts, tree frogs, and insects, undergo metamorphosis as they develop from the egg to the adult. The insects like the bee, house fly, mosquito, butterfly, moth, beetle, ant,

wasp, and flea pass through definite stages in their metamorphosis from egg to adult. These stages are known as (1) egg, (2) larva, (3) pupa, and (4) adult or *imago*. Figure 115 shows the appearance of some of the insects in their different stages. When the pupa changes into an adult, the insect is full grown. Table 5, on page 134, gives the length of time required for these stages in some of the common insects.

**SUGGESTED ACTIVITY.** If you have an opportunity, go into the woods and collect as many specimens of cocoons as you can find. Bring them to class and see if any of them will develop into adult animals.

Some insects do not pass through all of these stages. The grasshopper, for example, is said to have *incomplete metamorphosis*; that is, the egg develops into an immature grasshopper without passing through the pupa stage (Figure 116). The young grasshopper is much like the adult, except that it has no wings. Such stage is usually called the *nymph* stage. The eggs of the grasshopper remain in the ground throughout the winter and hatch the next spring. The nymph eats ravenously for several days and then sheds its skin, or *molts*. New skin is developed.

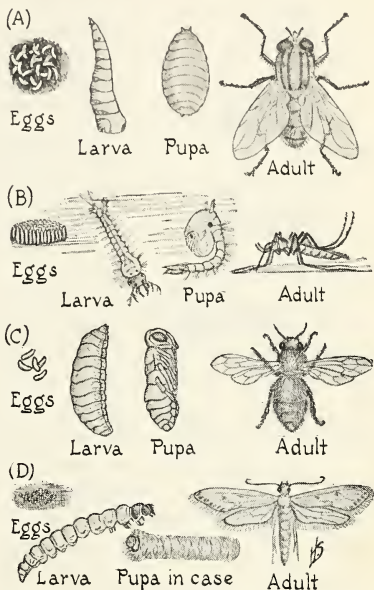


FIG. 115. Metamorphosis of the (A) house fly, (B) mosquito, (C) honeybee, and (D) clothes moth.

and the nymph again molts. After the fifth molting the grasshopper is full grown. Another striking case of incomplete metamorphosis is found in the cicada family of insects. One

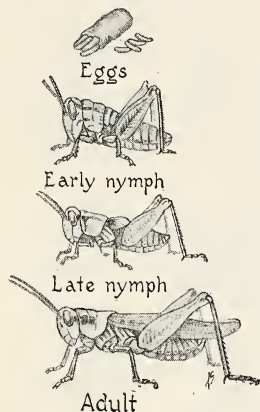


FIG. 116. Stages in grasshopper growth. Notice the beginning wings in the late-nymph stage.

of these, the seventeen-year cicada (sometimes incorrectly called the seventeen-year locust), lives underground as a nymph for seventeen years feeding on root juices, molting several times, and finally changing into an adult.

The eggs of the higher animals are really small cells. The "egg" which you have often seen, such as the "chicken egg" or "bird egg," includes much material in the form of the yolk and the white of the "egg." But the real egg cell forms only a very small disc (*germinal disc*) on one side of the yolk. Most of the so-called egg serves as food to the growing cell, just as the endosperm of the corn grain fur-

nishes food for the small embryo. In most of the viviparous animals the egg cells are very minute. In man the egg cell

TABLE 5. APPROXIMATE LENGTH OF TIME FOR THE PRINCIPAL STAGES IN THE DEVELOPMENT OF INSECTS FROM EGGS

| INSECT                 | EGG TO LARVA | LARVA TO PUPA | PUPA TO ADULT |
|------------------------|--------------|---------------|---------------|
| House fly.....         | 8-10 hr.     | 5 days        | 5 days        |
| Monarch butterfly..... | 4-5 days     | 1-2 wk.       | 1 wk.         |
| Cabbage butterfly..... | 5-8 days     | 10-14 days    | 7-14 days     |
| Mosquito.....          | 1-2 days     | 7-10 days     | 2-3 days      |
| Gipsy moth.....        | 9-10 mo.     | 1-2 mo.       | 1 mo.         |
| Honeybee.....          | 3 days       | 5 days        | 13 days       |
| Brown wasp.....        | 2 days       | 8-10 mo.      | 2 wk.         |
| Promethea moth.....    | 2 wk.        | 6 wk.         | 10 mo.        |
| Boll weevil.....       | 2-3 days     | 12-15 days    | 2 days        |

is less than one one-hundredth of an inch in diameter. So you see that you must not confuse the so-called egg with the real egg cell.

**Experiment 33.** What is the appearance of the germinal disc in a chicken egg? Allow an egg to stand for a few days on its narrow end. Then without moving the egg break away the shell and the inside membrane from the upper end; remove the white of the egg until you can see the germinal disc lying on top of the yolk. If you do this day after day with eggs that have been placed in an incubator and kept at about 100° Fahrenheit, you can watch the development of the egg cell into the young chick. This would require about two dozen eggs, because the period required for the development, called the *period of incubation*, is about twenty-one days for the chicken.

Figure 117 shows some of the stages in the development of a chick from the small germinal disc. The separate steps are too intricate and too many to describe here, but we shall mention a few. The first step is the division of the egg cell into smaller cells by *segmentation*, or *cleavage*. The entire egg cell divides into two cells, these two into four, these four into eight, as with the egg of the frog. Thus the original cell is divided into a large number of smaller cells, called *daughter cells*, each of which contains a nucleus and cytoplasm.

These daughter cells do not separate from each other as in the case of division of one-celled organisms. They form a hollow ball, called the *blastula*. In general, the blastula is one layer of cells thick; so all cells are in contact with the surface. The amount of material in the new cells is practically the same as that of the original cell. The daughter cells must, therefore, be very small.

The next step in development is called *gastrulation*. In this step, by a process of folding in, the cells form two layers, called *germ layers*. This is followed by the formation of another germ layer. Each of these layers gives rise to certain structures; that is, differentiation of the cells begins. The

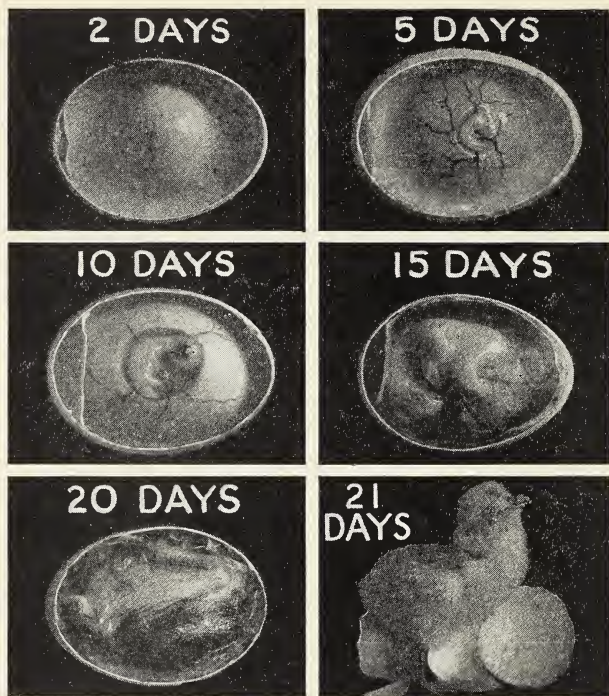


FIG. 117. Stages in the incubation of the chicken. What part of the egg contains the egg cell?

outer layer develops into the skin and the nervous system; the middle layer develops into the muscles, cartilage, tendons, bone, blood, and blood vessels; the inner layer develops into the linings of the digestive system, the liver, pancreas, and the respiratory system, including pharynx, bronchial tubes, and lungs.

The steps by which the egg cell, or embryo, of the chicken egg develops into a chick are quite similar to the changes

which take place in all of the common higher animals known as *vertebrates*, that is, animals having a backbone. How egg cells produce the germ layers, how the cells of these three layers divide and differentiate, how the various cavities in the bodies of vertebrates are formed, and how the different tissues and organs of higher animals are developed is the science of *embryology*. Perhaps you may some day study zoölogy, the science of animals, and also the special branch of zoölogy, embryology of animals. If you do, you will understand more fully how the various animals develop from eggs.

The periods required for the development of the eggs of different animals vary greatly. Table 6 shows the periods of incubation for some of our common birds. In Table 7 you will find the periods required for the development of the egg cells of different viviparous animals. The period necessary for the growth of the egg cell into the new-born animal is called the *period of gestation*.

TABLE 6. PERIODS OF INCUBATION OF BIRDS

| KIND OF BIRD     | INCUBATION PERIOD | KIND OF BIRD | INCUBATION PERIOD |
|------------------|-------------------|--------------|-------------------|
| Duck.....        | 26-28 days        | Swan.....    | 42 days           |
| Goose.....       | 29-31 days        | Chicken..... | 21 days           |
| Turkey.....      | 28 days           | Pigeon.....  | 16-17 days        |
| Guinea fowl..... | 28 days           | Canary.....  | 14 days           |
| Pea-hen.....     | 28 days           | Robin.....   | 14 days           |

TABLE 7. PERIODS OF GESTATION IN VIVIPAROUS ANIMALS

| KIND OF ANIMAL | GESTATION PERIOD | KIND OF ANIMAL    | GESTATION PERIOD |
|----------------|------------------|-------------------|------------------|
| Rat.....       | 21-28 days       | Goat.....         | 21-22 wk.        |
| Kangaroo.....  | 35 days          | Hippopotamus..... | 7½ mo.           |
| Opossum.....   | 20-26 days       | Pig.....          | 16 wk.           |
| Cattle.....    | 9 mo.            | Black snake.....  | 60 days          |
| Elephant.....  | 2 yr.            | Sheep.....        | 21-22 wk.        |
| Whale.....     | About 1 yr.      | Man.....          | 270-290 days     |
| Dog.....       | 62 days          | Horse.....        | 11 mo.           |

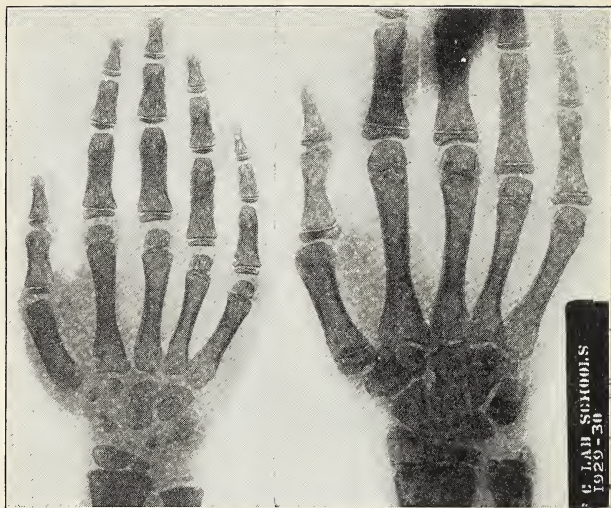


FIG. 118. X-ray photographs of the hand of a child at the age of six years, at the left, and of the same hand at the age of twelve, at the right. Notice how some of the cartilage, particularly in the wrist, has been replaced by bone.

Man's development is no exception to the general way in which higher animals grow from the egg cell to adulthood. Man begins life as a small cell in his mother's body. Slowly this cell divides, thus increasing the number of cells. The cells form the germ layers, and these develop into the various tissues and organs. When the embryo has developed for a period of from 270-290 days, it is born. After birth, the infant goes on growing. He grows taller. His muscles and bones increase in size. The proportions of the different parts of the body change. His finger-nails and toe-nails increase in size, more hair appears on his head, and teeth develop in his mouth. The first teeth are lost, and a new set takes their place. The facial features change. The

*cartilage* in different parts of the body is replaced by bone, which is added to the skeleton (Figure 118). Gradually the child changes into a young boy or girl, then into a young man or a young woman, and later into an aged man or an aged woman.

The study of the growth of many animals reveals several interesting facts. The lowest organisms grow regularly under favorable external conditions and require only a short time to reach maturity. The paramecium, for example, is full grown in twenty-four hours or less. In the higher animals the rate of growth varies at different stages, and each kind of animal begins to decline in vigor and growth after a certain period. The length of this period differs for each kind of animal. Some of the vertebrate animals, such as snakes, alligators, and fish, continue to grow in size as long as they live.

The highest animals, the mammals (those that suckle their young), seem to have definite growth limits and usually attain a maximum size long before old age overtakes them. It is thought by scientists that the waste products of cell growth and the weakening of the parts of the cell are the causes of decline, or *senescence*. The whole matter of growth is, of course, a question of anabolism and catabolism. As long as anabolism exceeds catabolism (see page 122), growth continues. In time, however, the destructive process (catabolism), exceeds the constructive process (anabolism), resulting in senescence and finally death. The products of the destructive process begin to accumulate as soon as the life of an organism begins. In a sense, then, animals begin to die as soon as they begin to live.

Among the more complex animals we find life spans of various lengths. Table 8, on the next page, gives the results of some studies on the ages of these higher animals. Unusual ages are given in the third column. The question marks which appear after some of the figures indicate that the life span shown by the figures is doubtful. It is worthy of note that many of the unusual figures in the third column refer to wild animals in captivity.

TABLE 8. LENGTH OF LIFE IN YEARS OF SOME COMMON ANIMALS

| ANIMAL        | USUAL AGES | EXCEP-<br>TIONAL | ANIMAL       | USUAL AGES | EXCEP-<br>TIONAL |
|---------------|------------|------------------|--------------|------------|------------------|
| Toad.....     | 4-8        | 36 (?)           | Pheasant.... | 20         |                  |
| Frog.....     | 10-12      | 76 (?)           | Rabbit.....  | 5-7        |                  |
| Crocodile.... | 175        | 200              | Guinea pig.. | 5-7        |                  |
| Tortoise....  | 175        | 200              | Cat.....     | 8-9        | 18               |
| Salmon.....   | 100        |                  | Lion.....    | 12-15      | 30               |
| Pike.....     | 150        | 267 (?)          | Tiger.....   | 15         | 30               |
| Crayfish....  | 4-5        |                  | Horse.....   | 25-30      | 40               |
| Goose.....    | 50         | 100 (?)          | Sheep.....   | 10-12      |                  |
| Swan.....     | 50         |                  | Camel.....   | 40         |                  |
| Raven.....    | 50         | 180 (?)          | Pig.....     | 20         |                  |
| Canary.....   | 20         |                  | Bear.....    | 40         | 100 (?)          |
| Thrush.....   | 8-9        |                  | Elephant.... | 100-200    | 400 (?)          |
| Pigeon.....   | 20         |                  | Whale.....   | 300-400    | 1000             |

**Self-testing exercise 5.** Write a composition of about two pages in length in which you compare the growth of a seed into an adult plant with the growth of an egg into an adult animal. So far as possible make the comparison in terms of the cell nature of growth.

#### PROBLEM 4: HOW IS THE GROWTH OF LIVING THINGS REGULATED?

**STUDY SUGGESTION.** In this problem you will summarize what you have already learned about the materials and conditions outside living things upon which growth depends. In addition, you will consider certain conditions within organisms which regulate growth.

In your study of biology up to this time you have found that living things need for growth certain materials, like food, water, carbon dioxide, and oxygen, and certain external conditions, such as light and heat. If the organism, which begins life as a tiny cell, is not provided with these materials and conditions in proper amounts, it cannot grow into a normal healthy adult. In addition to these materials and conditions there is another important factor in growth, namely, the actions of certain glands. But first let us consider the effect that food has upon the growth of the living thing.

How does food affect the growth of living things? Perhaps the most important single factor regulating the growth of living things is the kind and quantity of food taken into the body. For a great many years man has been experimenting upon animals, and as a result of this experimentation he has been able to determine with exactness the rations which should be fed to them. In general, the method employed is that of (1) selecting animals of the same size, age, and, if possible, of the same parentage; (2) feeding these animals upon different diets; (3) recording gains in weight, length, changes in bone structure, and freedom from disease;

(4) comparing the records of the animals to determine the effects of the different diets; and then (5) drawing conclusions as to the most efficient diet upon the basis of the records obtained. Similar experiments are also carried on with plants by varying the kinds of soils and the kinds of minerals in the soil. Let us now consider a few of these experiments having to do with the effects of certain food materials on the growth of living things.

The graph in Figure 119 presents an interesting example of varying the kind of food. Note that at the beginning of the experiment Rat A weighed slightly more than Rat B. At the end of the experiment, however, Rat B weighed more than twice as much as Rat A. This difference in weight was produced in a period of twenty-four days. Figure 120 shows the skeletons of these two rats. Note the difference in the

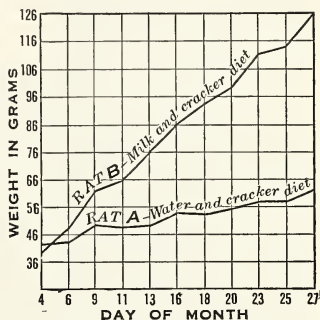


FIG. 119. A graph record of rat growth as affected by diet.\*

\*The data for this graph and the accompanying discussion are from an unpublished study by Miss Z. Stevens, University of Chicago, and are used through her courtesy.

entire lengths of the rats, and in the ribs, vertebræ, and leg bones. The skeleton of Rat A shows clearly that it did not obtain enough calcium for the proper development of its bones. Rat B obtained calcium from the milk. The experiment shows very clearly one of the reasons why babies are fed on milk. Do you know what this reason is?

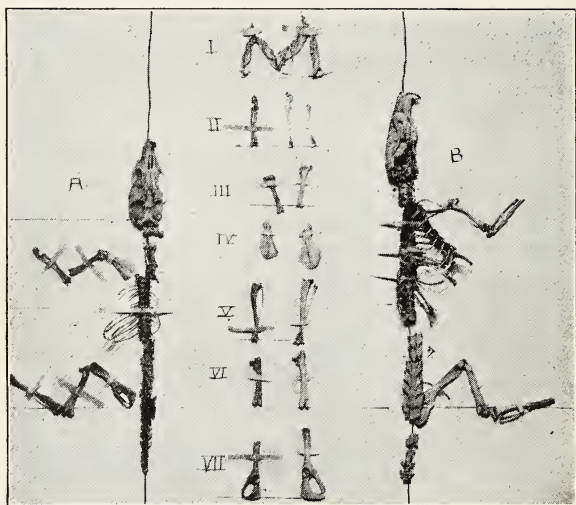


FIG. 120. Skeletons of rats fed on the diets indicated in the graph shown in Figure 119. I shows the jaw bones; II, III, and IV are the fore-leg bones; V, VI, and VII are the hind-leg bones.

Another type of experiment shows the effect of the diet of the mother upon its young offspring. Young animals of the mammal group obtain their milk from their mothers. Since this milk must be manufactured by the mother from the food which she eats, it is evident that the composition of the milk will be affected by what the mother eats. The effect of the diet of the mother upon the growth of the offspring is shown in Figure 121. The four young rats at the

top were nursed by mothers fed plenty of protein foods. Those at the bottom were nursed by mothers whose food was low in protein content. Note how much larger the upper four rats are. Experiments of this type have resulted in the production of standard diets for mothers, and have brought about a great improvement in the early growth of young mammals.

In his experiments with animals man discovers many strange things. For example, who would suspect that young trout will grow faster if a little dried skimmed milk or buttermilk is included in their diet! For years it was the custom to feed the trout in fish hatcheries upon a diet of raw liver. Raw liver is very low in its calcium content. If it were used as the main diet of a young pig or dog, for example, the result would be an

animal with poor bone development and a weak constitution. A search was therefore made for a food for young fish which would contain the necessary calcium. Of course, fish in their natural surroundings do not use milk for food, but trained students of diet decided to try milk because of its calcium content. Experiments showed that the inclusion of a small per cent of dried milk in the diet resulted in a rate of growth one-fourth faster than the growth obtained by feeding raw liver only (Figure 122).

The experiments just reported have shown the importance of food in regulating the growth of young animals. Similar experiments have also been carried on with human beings



FIG. 121. Effect of mother's diet on growth of young rats. (Cornell University Animal Nutrition Laboratory.)

with equally satisfactory results. The modern physician makes use of the data obtained from these investigations to prescribe the kind and amount of food which babies and growing children should eat.

**Self-testing exercise 6.** Prepare an outline in which you summarize the ways in which living things depend for growth upon various materials and conditions, thus:



FIG. 122. These trout were hatched from the same batch of eggs. Food alone accounts for the great differences that you observe in their sizes.

size the ways in which living things depend for growth upon various materials and conditions, thus:

(A) Materials

(1) Food

(a) Protein food is necessary to build protoplasm.

(etc.)

(B) Conditions (*Recall from previous units.*)

(1) Light

(etc.)

**How is growth affected by the endocrine glands?** We come now, in our consideration of internal materials and conditions affecting growth, to a special set of organs which have a great influence upon growth in the higher animals. These are known as the *endocrine* glands, or *ductless* glands, or glands of internal secretion.

You recall from Unit II that certain glands in the human body, such as the sweat glands and the salivary glands, open by means of ducts on the skin or on the mucous membrane of the digestive tract. These glands, as you know, manufacture certain definite substances which play a major part in making food materials usable by the body. In recent years biologists have discovered another set of glands which manufacture certain materials which are poured directly into the

blood stream, or into the lymph. These internal secretions contain substances known as *hormones*, which are chemicals needed to regulate the action of the various parts of the human body.

The *thyroid* gland, which is located in the neck, is one of the endocrine glands which has been studied most by scientists. It has three lobes, one on either side of the trachea and larynx and one just in front of the trachea. Although under normal conditions it weighs only about an ounce, the hormone which it secretes, called *thyroxin*, has a very great effect on growth.

If the gland is absent or does not develop properly, and if, therefore, thyroxin is not secreted into the blood and carried to all parts of the body, the growing child has a body temperature below normal, becomes physically inactive and mentally sluggish, and develops much fatty tissue over the entire body. This condition is called *cretinism*. Infants afflicted in this manner have large heads, the spaces between the cranial bones do not close normally, their teeth are slow in coming and readily decay, their bones are deformed, and their bodies are undersized. Fortunately, the condition, if detected early enough, can be remedied by feeding the child thyroid extract obtained from the thyroid glands of healthy animals. In some cases such feeding causes the undeveloped thyroid gland to grow to a normal size. If the gland is diseased, it may be necessary to give the extract continuously.

The effects of the hormone secreted by the thyroid gland are clearly shown in the cases of persons whose thyroid gland secretes an excess of thyroxin. In such persons one finds exactly the opposite effects to those which appear when the gland is lacking or not functioning properly. Persons afflicted in this way have body temperatures higher than normal, are mentally and physically alert, and, even though they eat much food and digest it readily, are usually lean and hungry.

A second gland which regulates growth is the *pituitary* gland, which is located at the base of the brain. This gland, although very small, secretes at least two hormones. The secretions of the front lobe of the gland have a marked effect on growth. If this lobe is enlarged in children, their



FIG. 123. This giant is over eight feet tall, yet he and some of the "midgets" are of the same age.

period of growth is lengthened, and they may grow into giants (Figure 123). If the anterior lobe of the gland fails to function, the physical growth of the child or young person is retarded. In such cases he is a dwarf. Fortunately, scientists have been able to obtain extracts of the pituitary glands of animals, which, upon being fed to children in carefully determined amounts, lead to normal development.

There are other endocrine glands which have effects upon the growth, health, and general development of human beings, such as the adrenal and parathyroid glands. The glands discussed above and their marked effects upon growth will give you some idea of the great importance of the endocrine glands. Perhaps you will want to know more about these glands and their hormones. If you do, consult books of the type of the *Encyclopaedia Britannica*.

**What conditions hinder growth?** And now let us turn from a consideration of the requirements for normal growth to a study of the conditions which hinder growth. Naturally, the absence of any of the requirements will slow down the

rate of growth, but there are also other materials and conditions which affect development. Foremost among these materials is a group of substances called *drugs*. Drugs may be divided into two classes, the *narcotics* and the *stimulants*. Narcotics, which include heroin, morphine, opium, and codein, act upon the nervous system and slow down its operation. They "deaden" the nerves. Stimulants, such as tobacco, tea, coffee, and alcohol, on the other hand, contain materials which act like a whip upon the nervous system and stimulate it to greater activity. Both narcotics and stimulants thus have a bad effect upon the nervous system. In addition to the effect upon the nervous system, drugs also interfere with the activities of the other systems of the body. Digestion is impaired, the circulation of the blood is interfered with, and normal respiration is affected. It is, therefore, upon the body mechanism as a whole that drugs have a harmful effect.

It is difficult for an individual to pick one particular effect of using the drug, and hence he does not believe he is affected by it. This is the main reason a person may use a drug so frequently that it becomes a habit. He is not aware of the effect of the drug or of the fact that he is getting to a point where he is a slave to the drug. You probably know people who use a moderate amount of alcohol, drink tea and coffee, and use tobacco. Apparently they are entirely healthy and are not affected by the use of these materials. Your judgment, however, is valueless. The effects of drugs are not visible to your casual inspection. The effects can only be determined by competent medical examiners through the use of scientific apparatus. The blood pressure must be measured, the rate and regularity of the heart beat must be examined, and the lungs and other organs of the body must be photographed with the X-ray. These are but a few of the many tests which must be made to detect the effect of drugs. It is these internal changes which are important in the correct functioning of all parts of the body. Drugs of any kind are detrimental to all animals. They are particularly harmful

to organisms during the process of growth. Since they interfere with the various functions of the body, normal growth cannot take place.

The normal growth of living things is also dependent upon the health of the various parts of the organism. The body of



FIG. 124. Blueberry plant growth.

an organism is a delicately adjusted mechanism, the efficient working of which depends upon the coördination of all parts. In many respects it is like other machines; if one part does not function, the machine as a whole will not function. You know that if the carburetor on a gasoline engine is not correctly adjusted, or if the valves stick, or if the "spark" in the cylinder does not come at exactly the right time, the engine will not deliver its maximum power. Neither will the human body develop its maximum efficiency unless each part of the body is in a healthy condition. The digestive, circulatory, skeletal, respiratory, excretory, nervous, and muscular systems must all

be in good working order. These various systems must not be overtaxed or injured, for if any one is harmed, the others will also be affected. Proper exercise and sufficient rest are necessary to keep these different systems at their maximum efficiency. Like the working parts of an engine, they all demand their share of attention.

It has been pointed out that the body of an organism is a delicate mechanism in which all parts must be in good working order if growth is to be normal. In the higher plant this means that the roots, stem, branches, and leaves must all be able to carry on their various processes. If any of these parts is injured, growth is hindered. Thus, if the

root system is injured by cultivating the land too near the plant or by careless transplanting, the plant cannot obtain the necessary water and minerals. Again, if the branches and leaves are harmed by wind or hail storms or by pruning the plant too much, the growth is hindered through lack of manufactured foods. Similarly, if the stem is injured through the removal of much bark by gnawing animals or by mechanical means, or through the destruction of the stem by insects, fungi, or other living things, the food transportation system of the tree cannot function properly, and the plant cannot grow normally.

Furthermore, as you can readily understand, plants, like animals, must have those materials necessary for growth. Notice the two blueberry plants in Figure 124. One of them is so small that you can hardly see it in the picture. The difference in size of the two plants was caused by differences in materials in the soil. In later units you will learn in detail what these materials needed for growth are.

Normal growth, then, is regulated by the proper functioning of all parts of the organism and by the presence of certain essential materials and conditions.

**Self-testing exercise 7.** Make a series of statements which tell what you can do to regulate the growth of living things, including yourself, by controlling the external conditions and materials which affect growth, thus:

1. I can water the house plants regularly, giving them the proper amount of water each time.

#### ADDITIONAL EXERCISES

1. Collect as many seeds as you can obtain, and make a display of them properly labeled. It will be interesting for you to make a sketch of the adult plant for each seed.

2. Make a chart in which you show by drawings the differences between the very young and the old stages of common animals. This will make a good exhibit for your class while studying this unit.

3. Collect information from the proprietor of a seed store, a gardener, and others concerning the length of time it takes for different flower and garden seeds to germinate. Arrange your facts in a table properly labeled.

4. Visit the keepers of animals and those who are interested in plant growth and learn what they consider important to know about the growth of living things. Prepare a report.

5. Write to your city or provincial health department for a Height-Weight-Age table. Then obtain from the school office your record of height and weight for as many years as you can. Compare your height and weight at different ages with the averages for boys and girls.

6. Plant seeds or bulbs of different kinds of plants not studied in Unit III and watch the stages of development of each plant. Make drawings to show the various important changes in structure.

7. Keep a time record of the important changes which take place as some "baby" animal grows into an adult animal.

8. With the help of your teacher plan experiments to test different seeds for starch, protein, and fat.

9. Obtain from a garden or weed patch a plant which you have removed from the soil very carefully without breaking off any roots. Measure approximately the total length of the root system of the plant and compare it with the total length of the stem and branches.

10. Weigh a pup or a kitten from day to day for a month. Prepare a graph to show the results of your experiment.

11. Obtain shoots from the following trees: maple, ash, poplar, basswood, and elm. Compare the shape of the shoots and the branching habits of the trees. This can best be done by making a drawing of each shoot and of the general shape of the tree. What effect does the position of the buds on the branch have upon the shape of the shoot and the branching habit of the tree?

## UNIT IV

### HOW DO LIVING THINGS MAINTAIN THEIR KIND?

#### PRELIMINARY EXERCISES

1. Name two plants that reproduce by cleavage.
2. Name five plants that come from eggs.
3. Name ten animals that come from eggs.
4. What is the chief function of a blossom?
5. Copy the letters (a) to (f) in a column. Opposite each letter write the names of plants or animals that could be used to complete the statement so lettered.
  - (a) ..... and ..... have many young.
  - (b) ..... and ..... usually bear only one young at a time.
  - (c) ..... and ..... bear many asexual spores.
  - (d) ..... and ..... bear many seeds that are scattered by the wind.
  - (e) ..... and ..... give no care to their young.
  - (f) ..... and ..... give much care to their young.
6. In what ways do plants aid their young?
7. In what two ways are a bird's egg and a grain of corn similar?
8. In what two ways is it an advantage to a plant or animal to have two parents?
9. Copy from the list below the best definition of a seed.
  - (a) An undeveloped plant.
  - (b) A fertilized egg.
  - (c) A protected embryo plant provided with food.
10. From the three possible answers given below, copy the correct answer to the question: What are the advantages of cross-pollination?
  - (a) More seeds are produced.
  - (b) Larger seeds are produced.
  - (c) The seeds produce better plants.
11. In what five ways does a young corn plant differ from an old corn plant?

12. State three ways in which animals supply food for their young.
13. Tell of three ways in which animals protect their young.
14. In what two ways is growth related to reproduction?
15. Why is the reproduction of plants and animals necessary?

### THE STORY OF UNIT IV

If one examines many of the ideas which people had only a hundred years or so ago, it is difficult to understand how

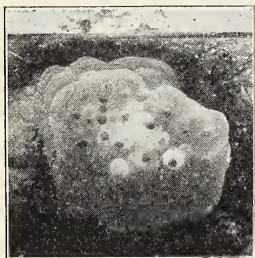


FIG. 125. A jelly-like mass of salamander eggs. (Geo. T. Hillman photo.)

they could have believed as they did. We must recognize, however, that many of the complex devices, such as the microscope and delicate instruments for weighing and measuring, are the products of comparatively recent times. Until the invention and perfection of these devices was accomplished, progress in science was exceedingly slow and difficult. Facts that are common knowledge to you were sealed mysteries until man brought to his

aid the powerful eye of the microscope.

One of the problems which has fascinated scientists of all ages is, "How does life originate?" As a matter of fact, we cannot answer this problem today, but we do know very much more about how new individuals come into this world than did the scientists of a hundred years ago. Up until the middle of the nineteenth century some biologists believed that life could arise spontaneously, that is, from non-living materials without the intervention of other living things. The ancient Greeks, for example, believed that certain animals, such as frogs and salamanders, were developed from mud at the bottom of bodies of water. Aristotle, a great Greek thinker, decided that plant lice developed from the dew on plants. Another belief in "spontaneous generation" was based on the fact that *maggots* (larva, Figure 115)

appeared on decaying meat and developed into blowflies. The early biologists believed that these blowfly maggots simply grew from the decayed meat. It was not until the latter part of the seventeenth century that an Italian scientist, Francesco Redi, overthrew the belief that these flies arise spontaneously.

Redi observed how flies behaved on the meat, and finally decided that there might be some relation between the flies and the maggots which appeared. So he covered the meat, preventing the flies from coming in contact with it. It

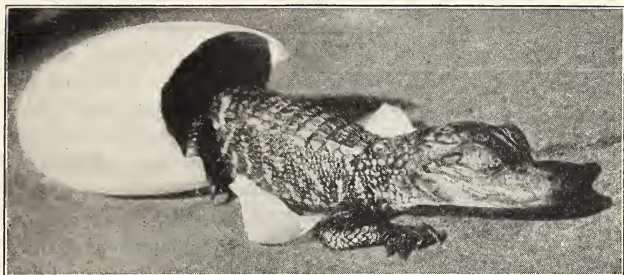


FIG. 126. It hardly seems possible that this young alligator could have been curled up inside the shell of the egg. (Herbert photo.)

decayed as usual, but no maggots appeared. He then covered the meat with a fine gauze so that flies could catch the odor of the meat. This attracted the flies, but they were prevented by the gauze from actually touching the meat. In this experiment maggots developed, but they appeared on the gauze instead of upon the meat. Of course, what happens is that flies frequently deposit their eggs on meat; these hatch and change to maggots, developing later into adult flies. Up until the time of Redi no one had discovered what really took place; so people thought that the maggots simply grew from the meat.

Even after these experiments were performed, the idea of spontaneous generation still held on. The invention of

the microscope in the seventeenth century had made possible the discovery of tiny plants, bacteria, and equally tiny animals. While scientists were entirely willing to admit that flies did not arise by spontaneous generation, these

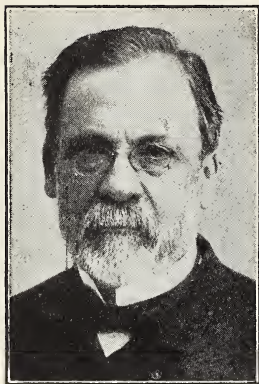


FIG. 127. Louis Pasteur holds the gratitude of mankind for his discoveries. Try to learn more of his great work from an encyclopaedia.

exceedingly small living things apparently just appeared from nowhere in liquids. Many biologists believed that the more complex organisms then developed from them. It remained for Louis Pasteur, the distinguished French scientist, to prove clearly that these microscopic plants and animals did not arise spontaneously.

Since bacteria ordinarily thrive and multiply rapidly in materials such as soups, men of Pasteur's time believed that soups and like materials were the natural environments in which such organisms originated. So Pasteur heated soup to a high temperature, killing any organisms which might be present. Then the soup was sealed

in a tube so that neither air nor bacteria could enter. He also heated soup in a tube and then plugged it with cotton. The cotton prevented the entrance of bacteria, but did not shut out the air. Under these conditions bacteria did not appear in the soup. Thus Pasteur proved that they do not develop spontaneously, but that they develop only if living organisms are present in the soup.

Many other experiments have been carried on since these experiments of Pasteur, and we now know definitely that the living things which come into existence today come from other living things of the same kind. From life comes all life.

Our problem in this unit is not to speculate how life first began, but to learn how the organisms living today get their start in life—how they reproduce themselves. In Unit III we learned that all living things begin as a single cell, and that the later growth and division of this original cell result in the development of the adult organism. In this unit we are concerned with the origin of this cell which develops into a new living thing. We shall see what it is that makes the cell begin its development. As you study this unit, you will find also that there are several modes of reproduction, but that they all have as their purpose the production of a new organism.

No fairy tale can be more fascinating than the true story of how all crea-

tures on the earth begin as a single microscopic cell. A great scientist once estimated that all of the plants and animals now living on the earth could have been contained in a teapot when they started their lives. A thimbleful of trees in the one-celled stage would be quite enough to reforest all of the land in our country from which the trees have been removed.

Reproduction, as you can see, is necessary for the continuation of a species or race. Living things ultimately become old and die, and if the race is to continue, their places must be taken by new individuals. If the rate of reproduction is greater than the death rate, then the numbers of a given species increase. If the reverse is true, the species



FIG. 128. Do you know the names of the different parts of this lily flower, and can you tell how the flower aids in reproduction? You will learn in this unit. (Geo. T. Hillman photo.)

finally disappears. We shall, therefore, in this unit also discover some of the ways in which nature has provided for the care of young organisms, because through parental care

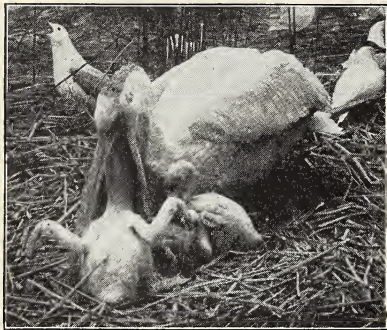


FIG. 129. This mother pelican is feeding her young by bringing up into her throat food which she has partly digested. The pelican lays only two eggs in a season. (American Museum photo.)

the death rate is decreased. This unit thus deals with the modes of reproduction and with the provision of conditions for a favorable start in life.

This unit will help you to understand one of the most wonderful chapters in the great cycle of life—how living things maintain their kind. And since reproduction is a biological necessity if life is to continue on our

earth, an understanding of the problems of this unit is essential to an understanding and appreciation of life itself.

### PROBLEM 1: WHAT IS THE NATURE OF REPRODUCTION?

**STUDY SUGGESTION.** Before beginning the study of this problem, recall what you have learned of how growth takes place. If necessary, review Problem I of Unit III.

You already know something about the process of reproduction. In Unit III you learned that one-celled plants and animals divide, forming two cells, each of which grows into a new organism. Since this division results in an increase in the number of organisms, *reproduction* has taken place. Reproduction is essentially a kind of growth—a growth in which one part of the organism is detached from the parent and grows into a new organism.

Reproduction in simple animals, such as the amœba, and in simple plants, such as the bacteria and *Pleurococcus* (page 110), takes place by division, or *binary fission*, as it is called. This division of one organism results in two separate, individual organisms, complete in all their parts. In an animal such as the paramecium many changes must take place in the cell before division occurs, because the cell contains several distinct parts. If you will compare the upper and lower half of the paramecium just before division (Figure 130), you will observe that all of the essential parts of the animal are present in both parts. The mode

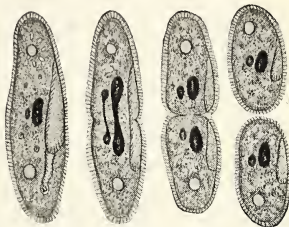


FIG. 130. Binary fission in the paramecium.

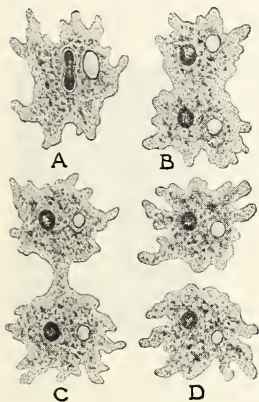


FIG. 131. Binary fission in the amœba.

of reproduction in the paramecium is exactly the same as in the amœba or bacteria, but the process is slightly more complex because of its more complex structure. The two daughter paramecia are not exactly alike, because they have been formed from different regions of the animal's body. This difference soon disappears, and they both become like the parent.

Strangely enough, reproduction by binary fission takes place in some of the many-celled animals. It does not seem possible that an animal as complex as the flatworm (Figure 132) could reproduce by fission. Yet such is the case. This animal divides transversely. The front (*anterior*) portion of the animal *regenerates*; that is, it produces a new rear

(*posterior*) portion. This is accomplished by the division and growth of the cells. The posterior portion of the animal regenerates a new head, including eyes and brain, and the whole portion finally becomes reorganized into a new individual. Reproduction by fission is confined to the simplest plants and animals. Earthworms, starfish, crayfish, fish, reptiles, birds, and mammals do not reproduce in this fashion. Neither do the mosses, ferns, and seed plants.



FIG. 132. common among the sea anemones, jellyfish, and many other *invertebrate* animals, that is, those without backbones. It permits the parent to carry on its normal activities while the bud is developing to a point when it can take care of itself. When this time is reached, the bud separates from its parent and begins an independent existence.

Still another method of reproduction is exhibited by the common bread mold (Figure 134).

**Experiment 34.** How does bread mold reproduce? (a) Moisten a piece of bread and place it in a saucer. Cover the saucer and place it in a dark, warm place. Examine the bread from day to day, adding water when necessary to keep it moist.



FIG. 133. Notice the two buds near the base of the hydra. (Geo. T. Hillman photo.)

(b) Look for the appearance of black dots on the tips of the thread-like branches that grow on the bread. When these appear, transfer them to a glass slide, cover with a cover glass, and examine them under the low power of a compound microscope.

(c) Press the cover glass down slightly and move it a little so as to break the black balls open. Note the tiny round bodies (*spores*) which come from the balls.

(d) Sprinkle some of the spores from the black balls on a piece of moist bread, and then follow the directions given in (a). Do the

spores grow into new plants? Compare the time required to obtain a good *culture* of bread mold when the spores are planted, with the time required to grow a good culture by simply exposing the bread to the air. How do you account for the difference?

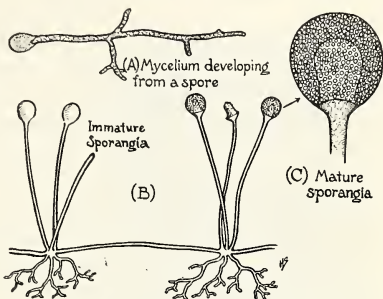


FIG. 134. Reproduction in the bread mold.

The black ball-like structure which appears at the tips of the white thread-like structures is known as the *sporangium*, or spore bearer. The spores are formed by the division of the protoplasm within the sporangium. Each sporangium usually contains about a hundred spores. When the sporangium wall breaks, the spores pass into the air. These spores possess heavy walls and also have food materials stored in them. They are thus able to live for a considerable time in the air. When you consider the thousands of spores produced by the bread mold which you raised, you can see why it is possible to expose a piece of bread to the air and be almost sure that one or more spores will fall upon it.

All of the fungi, that is, the rusts, mildews, smuts, mushrooms, and molds can reproduce by means of spores. The number of spores produced by the powdery mildews (which

grow on certain leaves) is so great that they appear as a cloud when the branch is shaken. It is this extensive production of spores which makes it difficult for man to rid his plants of these injurious fungi.

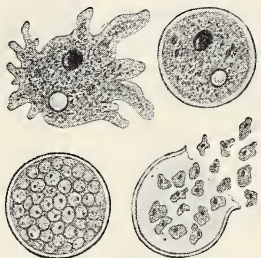


FIG. 135. Amoeba reproduction by spores.

Spore formation also takes place in some of the lower animals. The amoeba, for example, sometimes draws itself together in the shape of a sphere, around which a heavy wall forms. The nucleus divides and subdivides until as many as five hundred nuclei, each surrounded by a bit of protoplasm, may be formed. Under favorable conditions the wall breaks, and the spores are released, each one growing

within a few weeks to a full-grown amoeba (Figure 135).

The organism which causes malarial fever also reproduces by spores. The malarial-fever mosquito injects the fever parasite into the blood stream of a human being when its proboscis penetrates the skin. This parasite enters a red-blood corpuscle and soon begins to divide, ultimately forming from eight to twelve spores in the corpuscle. Finally the corpuscle breaks up, and the spores are liberated in the blood stream. Each spore then enters a corpuscle, and the same process is repeated. The time required for a complete cycle varies in different species of the parasite. In some species the time required is forty-eight hours; in others it is seventy-two hours.

Mention has already been made of the power of regenerating, that is, reproducing, missing parts. This power of regeneration is in reality a special kind of growth, but in certain circumstances it may result in the formation of new individuals; hence it is a mode of reproduction. An example will make this clear. The starfish (Figure 136) preys upon young oysters. The fishermen, knowing this, used to chop

the starfish to pieces when they caught them in their nets, and throw the pieces back into the water. Much to their surprise, however, the number of starfish increased. Later investigation showed that in one species of the starfish each of the arms could regenerate the missing parts; hence five starfish developed for every one which was pulled apart. The fishermen thus assisted instead of hindered in the propagation of more starfish. Experiments have shown that hydras, many of the worms, coral polyps, and sponges are capable of this power of total regeneration of missing parts from a single part.

As we pass upward from the lower animals to the higher ones, this power to replace lost parts becomes lessened. Sea cucumbers, relatives of starfish, and sea urchins, if disturbed or irritated, have the remarkable power of ejecting their internal organs and of reproducing them in a short time. Glass snakes, really legless lizards, when pursued by an enemy can snap off the ends of their tails. A new tail is soon regenerated. These odd devices may serve to save the lives of the sea cucumber and glass snake, for while enemies are pursuing the wriggling parts that have been thrown away, the owners escape. A crayfish may lose a claw, and a new one, although it is usually smaller than the original one, may grow to replace the missing one. But a crayfish will die if cut in two.

Higher animals such as birds and mammals cannot replace lost parts. If, for example, a wing, foot, or an eye is destroyed, no new one grows in its place. But new nails, fur, hair, and

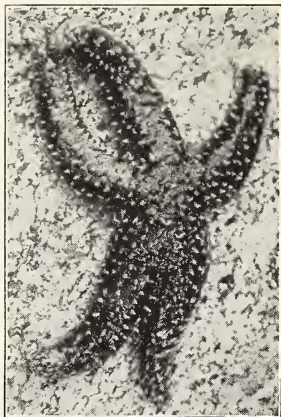


FIG. 136. A starfish. (L. W. Brownell photo.)

feathers usually take the place of those that are lost, and should a higher animal be wounded by having bones broken or small portions of the skin cut or torn, new cells promptly heal the injury.



FIG. 137. The potato produces seeds like any other plant, but it can grow roots and stems from the buds on its underground stem, called a *tuber*.

the mouth of a vase or a milk bottle. Keep the vessel filled with water. What happens?

(d) Hollow out the bottom of a large turnip. Hang it up near a window by means of strings fastened to thumb tacks or nails pushed into the turnip around the edge of the opening. Keep the hollowed place filled with water. What happens?

(e) Obtain a begonia leaf and cover the broken end with wet sand. Keep the sand moist, and observe what takes place.

(f) Obtain a potato. Note the buds ("eyes"). Cut the potato in such a way that each bud is

Man has long made use of the ability of plants to regenerate missing parts. If you carry out Experiment 35, you can see how it is accomplished.

**Experiment 35. How can new plants be produced by regeneration?** (a) Obtain some small branches from a willow tree. Place them in a milk bottle half filled with water. Examine the twigs several days later. Results?

(b) Make cuttings from geranium plants. Place in wet sand and keep in a warm place. Examine in about a week (Figure 138).

(c) Secure a sweet potato and push it part way into



FIG. 138.

surrounded by as large an amount of potato as possible. Plant the piece of potato in soil, and water it occasionally. Also plant a piece of potato which has no bud. What happens?

(g) Keep a careful record of any changes that occur in the willow, geranium, sweet potato, turnip, potato, and the begonia leaf.

Experiment 35 shows how roots may develop from stems and leaves, and how stems and leaves may develop from roots. One of the reasons why some of our weeds are so difficult to eradicate is because

they possess this ability to regenerate missing parts. If the roots of crab grass or goldenrod are cut, each part will regenerate stems and leaves and thus develop into a new plant. The only way, therefore, to get rid of them is to remove the whole root from the soil. In Unit VIII we shall see how man makes use of the power of regeneration to select and improve the kinds of plants which he wishes for food and other uses.



FIG. 140. Onion bulb regenerating roots and stems.



FIG. 139. The long, fleshy rhizome of the Solomon's seal. (Visual Education Service photo.)

Many plants, such as the potato, some species of violets, Solomon's seal, and lilies, store food in a fleshy, underground stem. These underground stems take various shapes. When they are elongated, they are called *rhizomes* (Figure 139). When the stem is enlarged rather than elongated, it is called a *tuber* (Figure 137). When the main axis is vertical and is enclosed by overlapping scale leaves, the stem is known as a *bulb* (Figures 140 and 141).

As the experiment has shown, these underground stems are able to reproduce by regenerating missing parts. These rhizomes, tubers, and bulbs are of great value to the plants which possess them because they are already in the soil and

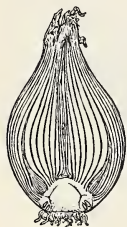


FIG. 141.  
Section of  
bulb showing  
thickened  
leaves.

because they provide an abundant food supply for growth. In these respects they are superior to the seeds which these plants produce. Seeds, however, are scattered over wide areas by the wind and other agencies, and hence are superior to the underground stem in producing a wide distribution. Some plants, such as the strawberry, produce horizontal stems (*runners*) at or slightly above the ground level. These stems take root at points where they touch moist soil, and new plants are developed (Figure 142).

All of the methods of reproduction described, binary fission, budding, spore formation, and regeneration, are essentially alike in one respect—each of them depends upon cell division. In simple, one-celled organisms division results in two distinct organisms. The buds produced by the hydra and other many-celled animals are produced by cell division and grow into mature organisms by continued cell division. The cells in the willow branch, geranium slip, and begonia leaf divide and replace lost parts, resulting in complete plants like the ones from which the parts were taken. Cell division in the sporangium of the bread mold produces spores capable of growing, through further cell division, into new plants. Reproduction, therefore, is only a special form of growth which takes place when a bit of protoplasm is detached from the parent organism and grows into a new individual. In the *amœba* the detached protoplasm is already a complete organism, and growth is simply an increase in size of the single cell. In the many-celled animals and plants the detached protoplasm must regenerate the missing parts, which together make up the complete organism.

In the methods of reproduction which have been considered, one or more cells are detached from a single organism and grow into new living things by cell multiplication. The types of reproduction described are known as *asexual* methods of reproduction.

Why these are called asexual methods can be best understood by a comparison of these methods with another mode of reproduction, *sexual reproduction*. In sexual reproduction there is always a fusion of two cells before growth of the new individual commences.



FIG. 142. At the nodes of the runners, roots grow down, and stems grow up. (Bureau of Plant Industry.)

After the two cells fuse or unite into one cell, cell division and differentiation take place, resulting in a new organism.

The difference between the asexual method and the sexual method is essentially only a difference in the way in which the detached portion of protoplasm, which grows into a new plant, is produced. In the asexual method, a cell or group of cells which are detached from the organism divide and through cell multiplication and differentiation produce a new individual. In the sexual method, two cells from the same organism or different organisms fuse, cell multiplication and differentiation follow, and a new individual is produced.

**SUGGESTED ACTIVITY.** Visit a greenhouse and find out how different plants are propagated.

**Self-testing exercise 1.** Summarize briefly the different types of reproduction discussed in this problem. Make a list of the advantages and disadvantages of each method. Save your answer to this exercise. You will need it to solve the exercise at the end of Problem 2.

## PROBLEM 2: HOW ARE THE MORE COMPLEX METHODS OF REPRODUCTION SECURED?

**STUDY SUGGESTION.** When we come to the higher plants and animals, we find that reproduction is a very complex process because it is associated with sex. To understand how sex affects the process of reproduction, we must first study some of the simpler organisms. This study will lay the foundation for an understanding of the more complex types of reproduction.

One of the common green algæ, *Ulothrix*, may be used to begin our study of the development of sex. At the end of the growing season, the cells in the plant body divide

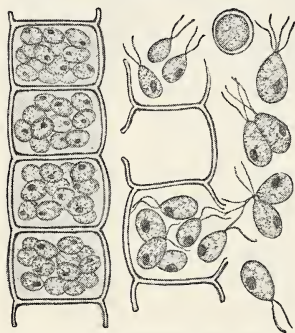


FIG. 143. Formation and discharge of gametes in the *Ulothrix*. The round body at the top right of the picture is the result of fusion of two gametes.

into a large number of small bodies. This division is similar to that which takes place when spores are produced, with this difference: the division is carried much further; that is, a far greater number of bodies are produced (Figure 143). These small bodies, or *gametes*, are discharged into the water, where they swim about, finally coming together in pairs and fusing with each other. The gametes differ from spores in that they cannot develop into a new plant until this fusion has taken place. The fusion of the two gametes thus presents a type of sexual reproduction in that neither gamete is capable, by itself, of growing into a *Ulothrix* plant. There is, however, apparently no difference between the two gametes which fuse; they cannot be distinguished as male or female.

*Edogonium*, another green alga, however, has two different kinds of gametes. Observe Figure 144 and note that

the gametes are produced in different parts of the plant. One gamete, the female, appears as a large rounded cell, and the other gamete, the male, is a small active body. The female gamete is known as the *egg*; the male gamete as the *sperm*. The sperm, which is equipped with cilia, swims to the egg; the wall enclosing the egg breaks, and the sperm enters and unites or fuses with the egg. The fusion of a sperm with an egg is called *fertilization*. The fertilized egg is capable of germinating and growing into a new plant. Without fertilization, it does not grow into a new organism.

Now let us turn to a study of the paramecium. We have already learned that paramecia reproduce by binary fission. After repeated divisions have taken place, however, a new event occurs in the life cycle of the animal. Two

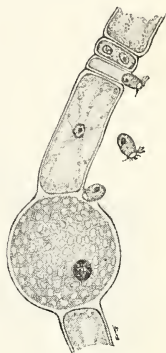


FIG. 144.

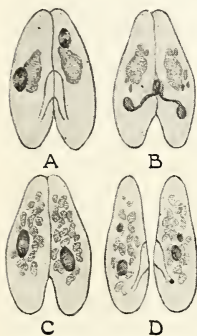


FIG. 145. Stages in the conjugation of paramecia.

paramecia come together, as shown in Figure 145, and a small bridge of protoplasm is formed between the two animals. During this attachment certain changes take place in the nuclei of the two animals, and they exchange nuclear materials. After the exchange is completed, the paramecia separate and go on living as before, except that they are now able to divide more rapidly. As time goes on, the rate of cell division decreases, and it is believed that it will eventually cease unless cell union of the paramecia, or *conjugation* as it is called, again takes place. Conjugation thus

results in a *rejuvenation* of the two paramecia, that is, in renewing the energy of the animal and making it more vigorous. So far as is now known, the two

paramecia which conjugate are identical; that is, they cannot be distinguished as male or female.

A process somewhat similar to that taking place in the paramecium occurs in the *Spirogyra*. Under unfavorable conditions, conjugation takes place between the cells of two different plants (Figure 146). Each cell puts out a protoplasmic bridge which joins with a similar bridge from a cell of a near-by plant. When these swellings meet and open, they



FIG. 146. Stages in the conjugation of *Spirogyra*. Note the completed zygote in the figure at the right.

form a tube through which the contents of one cell flow into the cell of its neighbor. The contents of the two cells fuse and form what is called a *zygote*. A heavy wall forms around the zygote, which enables it to withstand unfavorable conditions of temperature and moisture. When conditions become favorable, it germinates and produces a new plant. In some species of *Spirogyra*, one of the pairing filaments always discharges its contents into the other.

In the examples which have been given, several methods of sexual reproduction have been described. They are all similar, however, in that each method brings about a union of two cells or part of two cells. In the paramecium certain parts of the nuclei were exchanged and fused with those of the other cell. In the *Spirogyra* the entire contents of the two cells of different plants united. In the *Ulothrix* the small cells or gametes produced by the plant fused. In the *Cedogonium* two different kinds of gametes, produced in different parts of the plant, united to form a fertilized egg.

Now, this introduction of sex into the process of repro-

duction has far-reaching results: In sexual reproduction materials from different individuals come together and fuse. The new individual produced may, therefore, inherit characteristics from two parents. This possibility, as we shall see later, is of vast importance to the species.

Let us now pass on to a higher type of plant, the mosses. The sex organs of the mosses are produced on the tips of

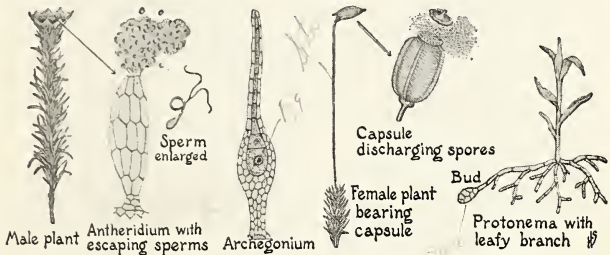


FIG. 147. Steps in the process of reproduction of a moss plant. The round object in the center of the archegonium is the egg.

leafy shoots. If these are examined under a microscope when the organs are developing, two types of sex organs may be found. Some species of moss bear both kinds of sex organs (*antheridia* and *archegonia*) on the same plant, while others bear only organs of one sex.

When the sex organs are mature, the wall of the antheridium bursts, and the thousands of sperm cells formed within escape. The sperm cells are equipped with two cilia (Figure 147) and can swim quite actively in the film of water on the moss plant. When they come in contact with the neck of the archegonium, they make their way down through the neck to the egg. The sperm then unites with the egg, and the act of fertilization is completed. The fertilized egg then commences to divide. It produces a *foot* which anchors it to the plant and enables it to obtain nourishment. It then grows a long, hair-like structure, the *seta*. The upper end of the seta enlarges into a *capsule*. The protoplasm in the capsule then divides and forms a large number of spores. When

the spores are mature, the capsule bursts, scattering the spores in all directions. The spore germinates if the conditions are suitable and forms branching filaments, the *protonema*. Some of the cells in the protonema divide and form a bud. These buds grow into a mature moss plant.

At this point we must note a difference in the process of reproduction in the simple water plants and in land plants. In the simpler plants living in the water, the distribution of the organisms was brought about by the swimming sperm. In land plants, however, this method could not be successful, since sperm cells cannot swim in the air. The mosses have retained the swimming sperm; hence, a film of water must be present so that the sperm can swim to the archegonium.

However, the mosses have added another step in the process to secure the distribution of the species. The fertilized egg does not grow into a plant like the parent, as happens in the simpler plants. The fertilized egg grows into a structure which can produce spores. These spores have heavy walls, and can be carried by the wind. Thus the moss is enabled to scatter its spores in the air and distribute the plant far and wide. The heavy wall of the spore prevents the protoplasm from drying and enables it to live until favorable growing conditions are present.

You are already familiar with the growth of the seed. You know that the seed contains an embryo, which under favorable conditions will grow into a new plant. How the seed itself is formed is another story. Because lilies are such common flowers and their parts are so easily studied, we shall use one as an example of how reproduction takes place in the seed plants.

**Experiment 36.** What parts of the lily are concerned with the process of reproduction? (a) Obtain the flower of any member of the lily family. If none is available, any simple flower, such as the petunia or primrose, will serve your purpose. Remove the showy outer part of the flower and, with the help of Figure 148, locate the *stamens*, *anthers*, *filaments*, *pistil*, *stigma*, *style*, and *ovary*. Make a diagrammatic sketch showing these parts. Label each part.

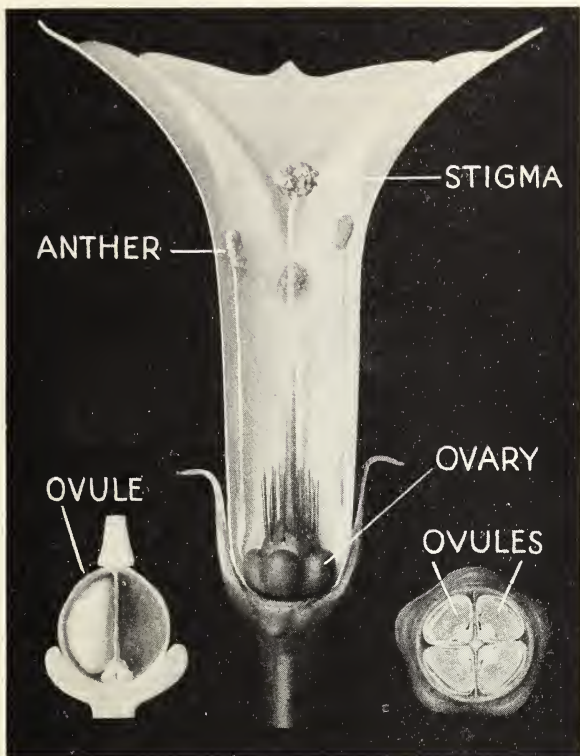


FIG. 148. Parts of a morning-glory flower. The stem supporting the anther is called the filament. Anther and filament together are called the stamen. The stem supporting the stigma is called the style. Stigma, style, and ovary together make up the pistil. The green leaf-like structure surrounding the base of the flower is the calyx. Its separate parts are called *sepals*. (Field Museum photo.)

(b) Cut across the ovary with a sharp knife or safety-razor blade. Note the number of compartments in the ovary. In the compartments you will be likely to find small rounded bodies, the *ovules*. Make a sketch of what you see.

(c) Examine an anther. Note the tiny yellow *pollen* grains.

As is true of the lily blossoms, the flowers of plants have as a special function, the reproduction of their kind. The essential organs for reproduction are the stamen and pistil. The tip of the stamen, the anther, contains pollen grains or spores which are formed by cell division in the anther. Within the ovary, cell division also produces certain kinds of spores. The spores formed in the ovary and anther differ

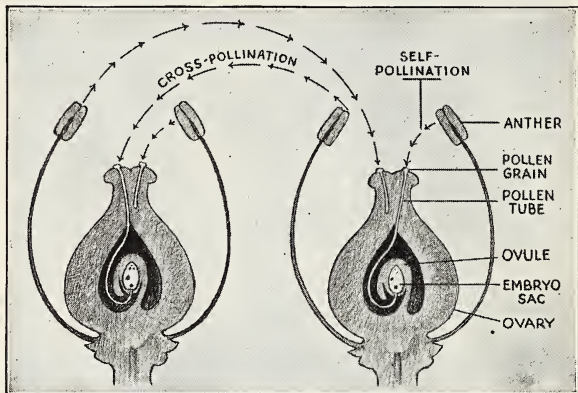


FIG. 149. How pollination of the flower is secured. Study the drawing carefully in order that you may understand how the pollen grain gets from the anther to the stigma. Note how the pollen grain germinates and works its way down into the embryo sac within the ovule.

from the spores produced by the moss in that they cannot grow into a new plant, as you will learn from the following explanation. When the pollen grain is ripe, it is ready to be transferred to the sticky, roughened stigma of the pistil. This transfer (*pollination*, as it is called) is brought about in a variety of ways, as we shall see later.

When the pollen grain is deposited on the stigma, its outer wall breaks, and its inner wall protrudes through the opening, producing a long tube which forces its way down through the style to the ovary (Figure 149). While

this is taking place, a process of development is going on within the spores produced in the anther and the ovary. As a result of this process, a male cell or sperm is produced in the pollen grain, and an egg is produced in the spore in the ovary. The pollen tube penetrates one of the ovules, and the sperm fertilizes the egg. In some plants there are many ovules. Each of these ovules contains an egg, and each egg must be fertilized. After fertilization, each fertilized egg begins to divide and finally forms an embryo within a hard, outer coat. Around the embryo a supply of food is stored. The whole makes up what we call a seed. The pistil in which the seeds are produced finally breaks, and the seeds escape. As a rule, seeds are produced in the autumn and lie on the ground over the winter until favorable growing conditions arrive.

We ordinarily think of fruits as being good to eat, but the word "fruit" has a different meaning in science. The ovary with its seeds is technically known as a *fruit*. Thus, in this sense there are winged fruits, such as in the elm and maple. Apples, pears, grapes, tomatoes, currants, melons, pumpkins, dates, cherries, and raspberries are examples of fruits. In some fruits other parts of the plant, such as the *receptacle* (the end of the stem on which the flower grows) and the *calyx* (the green, leaf-like structures at the base of the flower), surround the ripened ovary. Thus, the fleshy part of the apple, in which the seeds are found, is formed from the receptacle. The fruit furnishes protection for the seed during the time of its inactivity. It also helps secure dissemination

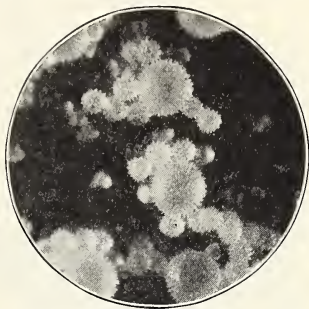


FIG. 150. Pollen grains highly magnified. The larger ones are from the marsh mallow; the smaller are from the dahlia. (Jesse L. Smith photo.)

of seeds. For example, birds carry fruit away and eat it. Later the seeds are voided and drop on the ground where they may germinate.

In this problem it has been possible to present only a few of the changes which have taken place in methods of reproduction. We have seen that sexual reproduction begins in the algæ where a swimming sperm unites with an egg cell of the same plant or of another plant. The mosses improved upon this process by the addition of another stage in the life

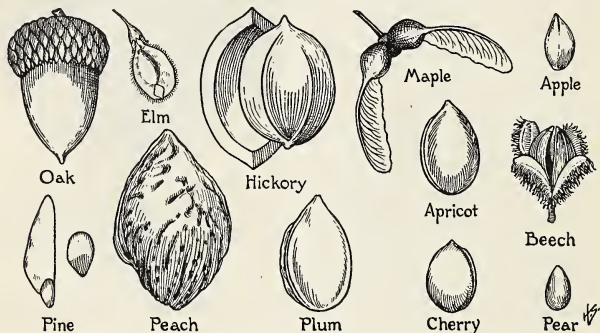


FIG. 151. Note the winged fruit of the maple, elm, and pine to help the wind carry the seeds. The oak, hickory, peach, and beech seeds are well protected by their hard outer shells.

cycle, the production of spores. Mosses, however, can live only in moist places, because it is still necessary for the sperm to swim to the archegonium.

The seed plants, however, have completely done away with the necessity of living in an environment where water is necessary for fertilization. In the seed plants the pollen grain containing the sperm cell can travel through the air. Furthermore, the production of a seed which can live through many years of unfavorable conditions and still be able to germinate when favorable conditions arise is of great benefit in the distribution of the plant. It is these changes in the mode

of reproduction which have made the seed plant the dominant plant of our environment.

**What are the advantages of cross-pollination?** We are now ready to consider some of the advantages secured through the introduction of sex into the process of reproduction. As you saw in Figure 149, page 172, there are two ways in which plants are pollinated: *self-pollination* and *cross-pollination*. In self-pollination the pollen from a stamen reaches the stigma of the same flower. Many plants, including wheat, have this method. There are a great many plants, however, that produce better seeds and, therefore, better plants when the pollen comes from the stamen of different flowers.

Charles Darwin showed, for example, that cabbages which were pollinated by pollen of the same flower for several generations weighed only about one-fifth as much as those which were cross-pollinated for several generations. Experiments with corn have also shown that self-pollination results in a decrease of from sixty to seventy per cent in yield after a period of six or eight years. In cross-pollination, of course, the pollen must come from the same kind of flower. Corn pollen, for example, can fertilize corn pistils (the silks), but they cannot fertilize oats or sugar cane.

Now let us see the advantage of cross-pollination to plants. The seed which is formed contains materials from two distinct plants; that is, the sperm comes from one plant and

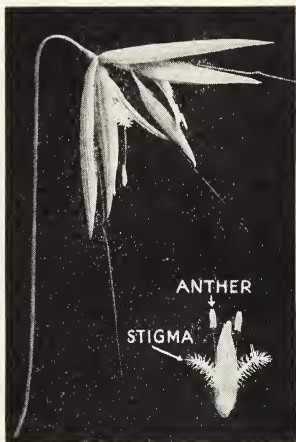


FIG. 152. The flower of the wild oat. Perhaps you have never realized that the grasses bear flowers, also. (Field Museum photo.)

the egg from another. The next generation will thus inherit characteristics from both of the parents. As you know, there are no two living things which are exactly alike. Since the parents differ, it is evident that the offspring will have characteristics which are not exactly like those of either of the parents. They will resemble the parents in general; that is, they will be plants of the same species, but they will differ from the parents in certain details. These changes take place generation after generation, and it is through these changes that new *variations* in the structures of organisms are possible.

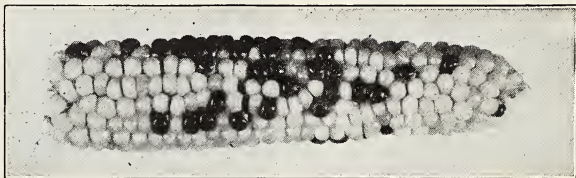


FIG. 153. This ear of corn grew on a plant that would normally bear white corn. However, this particular ear was partly pollinated by pollen from a plant that bore purple corn. The characteristics of both parents appear in the offspring.

At rare intervals one of the offspring will appear with a structure different from that possessed by the parents. Occasionally this structure will be helpful to the plant. Of course, any change or variation occurring in a given plant which fits that plant better to the soil, temperature, rainfall, or other environmental conditions, gives that plant a better chance to survive. It will therefore have a better chance to produce seeds and perpetuate itself. The introduction of sex into reproduction therefore, has, brought about a greater chance for variation, that is, for the production of new forms of structures which may better adapt the organism to the environment. As we shall see in Unit VIII, it is through this process of variation that man has been able to produce better plants and animals.

How do plants secure cross-pollination? If you examine plants, you will find that many interesting devices have been developed to prevent self-pollination and to secure cross-pollination. Of course, this does not mean that plants have developed these methods through thinking or planning. The methods have evolved through the variations which resulted and through the natural selection of those variations which proved to be advantageous to the plant.

In certain flowers, such as the geranium and sunflower, the pistils and stamens of a given flower mature at different times. This makes it impossible for self-pollination to take place. One of the oddest methods of preventing self-pollination, and one of the most effective, may be seen in the bluets and primroses. The flowers of one plant have long styles and short stamens; those of another plant have short styles and long stamens. Pollen from short stamens will fertilize only those pistils with short styles, while pollen from long stamens will fertilize only those pistils with long styles. The examples above represent but a few of the many different ways in which self-pollination is prevented and cross-pollination is secured.

In some plants cross-pollination is the only means whereby fertilization can take place. The reason for this is as follows: Each plant of the species bears only one kind of flower; that is, either a flower with pistils or one with stamens, but not both. Thus, one willow tree will bear *staminate flowers*, producing the pollen grains on the anthers. Another will grow *pistillate flowers*, with stigmas and ovaries (Figure 154).



FIG. 154. Flowers of the willow tree. Those at the left are pistillate; those at the right are staminate. (Fuller photo.)

The poplars, or cottonwoods, are also examples. This is why certain of the cottonwood trees do not bear the "cotton" which carries the seed.

Cross-pollination is also secured through the help of insects which visit flowers for pollen and nectar, which they use as food. As they flit from flower to flower, they carry pollen grains on their hairy bodies, and these are often deposited upon the stigma of another flower. Some plants are pollinated entirely by insects. Thus animals like the honeybee, going about their own business, assist in the life-process of plants.

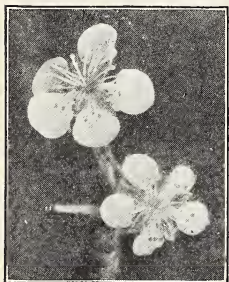


FIG. 155. A bee would have a difficult time alighting on these apple blossoms without getting pollen on its body.

**How do the higher animals reproduce their kind?** As we pass from the plant kingdom to the animal kingdom, we cannot help but notice the similarity of all living things. In the one-celled animals reproduction may take place by binary fission as

in the plants. You have already learned this in the case of the amœba and the paramecium. Some of the lower animals conjugate as do some of the lower plants. Reproduction may also take place through formation of spores in both the lower animals and the lower plants.

As we pass from the lower animals to the higher animals, an increased specialization of cells for reproductive functions is found. Many of the lower animals, such as the hydra and earthworm, bear both types of reproductive organs; that is, they produce sperm cells and eggs. In the hydra the sperm may fertilize the egg of the same individual. In the earthworm, however, a method of securing cross-fertilization has developed. Two worms come together, and each passes sperm cells to the other. These are held in small receptacles until the eggs are mature. Then, through

a rather intricate method, the sperm cells are brought in contact with the eggs, and fertilization takes place.

The higher animals may be classified as male or female; that is, each individual is capable of producing a sperm or an egg, but not both. The egg is developed in the female, and the sperm is developed in the male. The process of fertilizing the egg by means of the sperm is brought about in different ways, depending upon the type of animal. Some of these ways will be considered in the following paragraphs.

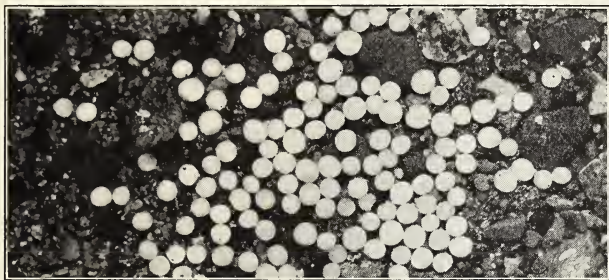


FIG. 156. Eggs of the brook trout, laid in a basin-like spot amid the gravel at the bottom of a quiet pool. (Lynwood M. Chace photo.)

The female fish lays thousands of eggs. She then goes away and leaves the eggs to their fate. The male fish comes along and deposits sperm cells among the eggs. He then goes on his way. Those eggs that are fertilized can develop into fish. Of course, it is possible that the eggs, or at least part of them, may never be fertilized. Those which are not fertilized die. The fish, however, lays such a great abundance of eggs that, even though but few of them are fertilized, enough of them hatch and grow to maturity to provide for new generations.

The mother fresh-water clam has a unique way of sending her young out into the world. Sperm cells from the male clam are thrown into the water through the outgoing siphon. They are taken into the body of the mother clam through

her ingoing siphon, where they fertilize the eggs. The young clams develop within the gills of the mother. When they have reached the proper stage of development, they are forced out into the water.

Like the fish, the birds and many other animals lay eggs, but the eggs are fertilized by the sperm cells before they leave

the body of the mother. The fertilized egg undergoes a period of development within the body of the mother, during which it is surrounded with food material for the growing embryo and is covered with a shell for protection before it is laid. After it is laid, it undergoes further development, resulting in the hatching of the young. In the mammals, such as the rabbit, horse, cow, and man, the eggs complete their development within the body of the mother, and the young animals are born alive.

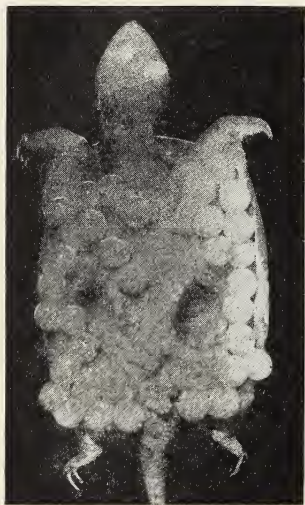


FIG. 157. Eggs found in the body of a snapping turtle. The large number ensures the survival of at least some offspring.

must divide. This multiplication of cells brings about increase in size, and the differentiation of cells eventually produces a mature organism.

**Self-testing exercise 2.** Make a comparison of asexual reproduction and sexual reproduction. What conclusion do you draw as to the advantages and disadvantages of each of the types of reproduction?

### PROBLEM 3: HOW DO PARENTS PROVIDE FOR THEIR YOUNG?

**STUDY SUGGESTION.** As you study this problem, note the differences in the amount of parental care given by different animals to their young. Also note the relationship between the mode of reproduction and the number of young produced with the amount of parental care necessary to bring the young to a point where they can take care of themselves.

When you came into this world, you were absolutely helpless. You could not feed yourself, you could not move from place to place unless someone carried you, and you could not even see what was going on around you. Left to yourself, you would have died. But, fortunately, your mother or your father or someone else looked after your wants until you were old enough to help yourself. Most of us rarely think about the care and energy which has been expended in order that we may grow and take our place in the world.

Of course, you know without being told that animals such as the *amœba*, *paramecium*, and *hydra* take no care of their young. As a matter of fact, in the *amœba* it is impossible to call either of the animals which are produced by fission the offspring. They are both young in the sense that they are smaller than fully mature *amœbas*, but they have all the essential structures of the adult *amœba* and can carry on all of the activities of life.

Many animals never see their young. The only provision which is made for them is that food is stored in the egg,

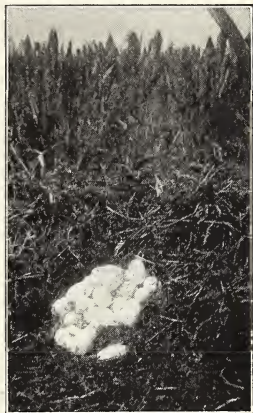


FIG. 158. The alligator lays its eggs on a mound of earth and rotting plant materials. No care is given them or the young. (Field Museum photo.)

which nourishes the young until they can find food. In this class of animals we find the earthworm, starfish, most of the fishes, the frogs, the reptiles, and many others. Most of these animals lay many eggs, some of them many thousands of eggs. A large number of these are devoured by other animals. A few of them, however, hatch. The young are fully able to take care of themselves so far as obtaining food is concerned. Many of them, of course, are eaten by other animals, but some of them grow to maturity. In spite of the lack of parental care, a sufficient number of these animals grow to maturity to keep the species from dying out. Two important factors are responsible for this: the large number of eggs produced and the ability of the young to take care of themselves as soon as they are hatched.

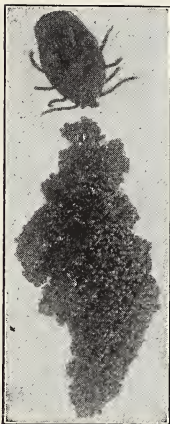


FIG. 159. Egg mass of a tick. More than a few will reach maturity.

**SUGGESTED ACTIVITY.** If you live near a body of water in which there are turtles, you may be able to find a nest by tracking the animal from the edge of the water to a scratched place in the sand several yards from the shore. If the eggs are kept covered with sand, you may have the pleasure of seeing some brand-new baby turtles.

Insects provide for their young chiefly by depositing the eggs in favorable places. Grasshoppers, for example, lay their eggs in the hardest soil they can find. This protects the eggs from the presence of too much water, which will cause the eggs to spoil. The hard soil takes up less water than loose soil, and it does not hold water so long. You perhaps are wondering how the grasshopper knows this. The answer is that she does not know it. Her acts are performed entirely by instinct. They are more automatic and involuntary than the blinking of your eye.

Many insects lay their eggs near a food supply which the young may find as soon as they hatch. The young of the blister beetle, for example, positively refuse to eat anything but grasshopper eggs. The blister beetle does not need to lay her eggs in the hard ground because they hatch in but a few days. She lays them, however, either on or near the hard ground near grasshopper eggs.

Just as soon as a baby blister beetle hatches out, it stretches its legs and off it goes in search of a grasshopper's nest. How it can locate the nest is a mystery, but hunger must help, for if there is a nest within reach of the beetle's active legs, it is sure to find it. It then rapidly digs its way

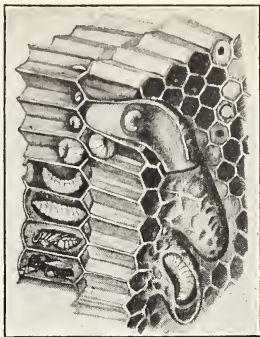


FIG. 160. The honeybee takes elaborate care of its young, in a carefully constructed home. At the left are eggs, pupa, and larva. At the right are the compartments for the queen bee, whose sole duty is to propagate the species.



FIG. 161. The wasp makes a nest for her eggs, deposits food in each cavity, and then closes the cavities. (Geo. T. Hillman photo.)

into the egg *follicle* or cell, and even though a grasshopper's nest generally contains from twenty to thirty eggs, it never stops till all are devoured.

Many other insects besides the blister beetle deposit their eggs in locations near a food supply for the young. Cabbage butterflies lay their eggs on the underside of cabbage leaves, and when the young hatch, they are in the midst of a plenteous pantry. Flies lay their eggs on decaying meat, or on manure piles, or in garbage. Scarab beetles or tumblebugs deposit their eggs in manure and roll it into a ball which sup-

plies food for the young when they hatch out. The swellings on plants where the eggs of gall flies have been laid supply food and protection for the young. Ichneumon flies place

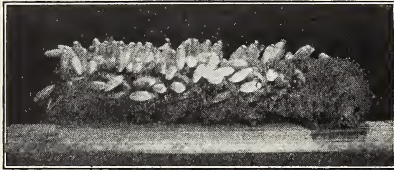


FIG. 162. Insect cocoons on a hawk-moth larva. When hatched, they eat some of the flesh of the larva; but strange to say, they do not injure it. (Geo. T. Hillman photo.)

their eggs either on or under the skin of the larvæ of other insects, and fresh meat is thus provided for the young. The aphision or lace-winged fly provides for the protection of her young in an odd and interesting way. Each

egg is fastened at the end of a silken stalk, and the stalk is attached to a leaf. This device prevents the cannibalistic young from devouring the eggs that contain their brothers and sisters that have not yet hatched out.

Certain spiders provide food for their young in a way that illustrates survival of the fittest as well as the fattest. The mother spider lays her eggs in a silken cocoon which she carries about with her for a time, finally hiding it in a secluded place. The eggs hatch out within the silken case, and here the larger, stronger young eat their smaller brothers and sisters. When the case is finally opened, a few large, strong young spiders step out to take their places in the world. Another way in which mother spiders provide for their young is by permitting them to ride



FIG. 163. Egg cocoon of the golden spider. (Lynwood M. Chace photo.)

on her back until they are large enough to take care of themselves. Sometimes the children are so numerous that they almost completely cover the mother.

Most fish make no provision for their young except that there is food stored up in the eggs. The devotion of parents to the welfare of their children, however, is well illustrated in the case of one fish, the salmon. This fish lives in salt water, but the eggs must be laid in fresh water. This makes it necessary for the parents to travel great distances up the courses of swiftly flowing streams. In swimming among stones and over rocky waterfalls their bodies may become so bruised that they die from the injuries after spawning. Eels, on the other hand, live in fresh-water streams, but their eggs will develop only in salt water. When the parents are ready to *spawn*, they travel down the streams hundreds or even thousands of miles and far out into the ocean. Here the eggs and sperm cells are deposited, after which the parents die.

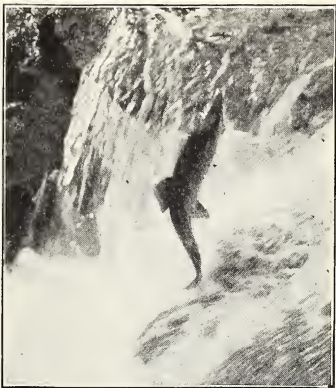


FIG. 164. This salmon may make many such leaps before clearing the falls.

Although most fish pay no attention to their young after they are hatched, there is, however, one plucky little fish, the stickleback, that builds a nest. Here the eggs are guarded by both parents, and the young are protected until they can care for themselves.

The birds present some interesting examples of care of the young. Except in a few cases, such as the cow bird, the parents construct some kind of a nest in which the eggs are deposited. The eggs are incubated by the body heat of the

father and mother, who often take turns sitting on them. At such times it is not unusual for the father to feed the mother as she sits on the nest. When the eggs are hatched, the young birds are fed until they are old enough to leave the nest and forage for themselves. The young of perching birds, such as the robin and bluebird, are naked when they are hatched; therefore they must be protected from cold, the



FIG. 165. The Canada goose sits peacefully on her nest while the gander stands guard. Note the tufts of white near the nest. They are bits of down which the goose plucked from her breast to line the nest. (Lynwood M. Chace photo.)

sun's rays, and rain until they feather out. Scratching birds, like the quail and barnyard fowl, are covered with down when hatched and are able to walk and run soon after they come out of the shell.

The young are not only fed and covered, but the parents protect them from enemies of various kinds. Should a hawk or crow come near the nest of a purple martin, the parents promptly and fearlessly give chase to the larger bird. Many birds, especially those that have several young in their broods, as for instance the chicken hen, have certain calls

for calling and warning their young. A slow cluck tells them "all is well." A series of rapid clucks bids them come for a morsel of food, while a loud *crrrrr* sends every chick scurrying to a safe hiding-place. The "language" of chickens, quails, and other birds is a fascinating study.

Feigning crippledness is a unique device employed by some birds in protecting their eggs or young. Should a dog or other animal come too near the nest or young of a quail or snipe, the mother flutters along in front of the marauder in a seemingly crippled condition. In following the mother with a "broken wing," the enemy is led some distance from the



FIG. 166. This mother warbler is shielding her young with her wings. (L. W. Brownell photo.)

precious nest or fledglings, when—*whirrr*—the broken wing is healed instantly, and the dog with open mouth just ready to seize his prey is left to lick his hungry chops.

**SUGGESTED ACTIVITY.** Collect abandoned nests, and examine the materials used in the construction of the nests. Prepare a careful list of all of the kinds of materials used.

**SUGGESTED ACTIVITY.** Observe robins selecting the nesting site.

(a) Do both birds help in the building of the nest?

(b) What materials are used?

(c) It is said that two robins' nests are never placed in the same tree. Verify or disprove this statement.

When we consider the group of animals to which we give the name "mammals," we find evidence of still more care and protection for the young. The mother rabbit, for example, about the time for the birth of the young, digs a hole in the ground which she carefully lines with grass. To this she adds

fur plucked from her body. Into this soft, warm nest she deposits her blind, deaf, and hairless young. Manifestly these young rabbits need parental care. If left alone, they would die of starvation; or if they should come out of the nest, they would fall easy prey to other animals. The mother rabbit, however, covers the opening to the nest with sticks and grass before she leaves it. When it is dark, she ap-

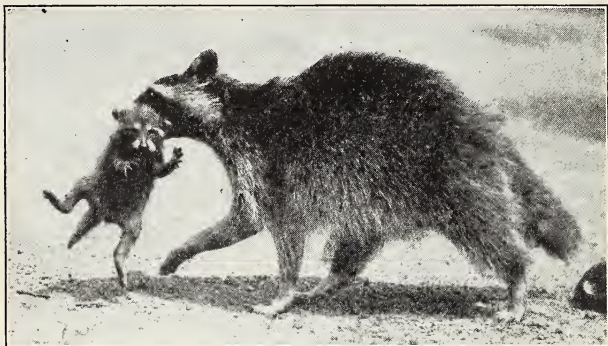


FIG. 167. The mother raccoon, like the cat, carries her young by the nape of the neck. (Lynwood M. Chace photo.)

proaches the nest cautiously and removes the covering. She then takes the young rabbits out of their nest and nourishes them with milk from her body. When they get a little older, she takes them with her to choice food patches.

Some animals apparently teach their young. The cat will cripple a mouse so that it cannot escape, then bring it to her young. The kittens practice jumping for the mouse and try their teeth and claws upon it. The fox takes her young when she goes hunting, and the young foxes learn how to capture their own food. As far as we know, however, the cat and fox are not conscious of any attempt on their part to teach their young. It is purely an instinctive reaction, a tendency which they have inherited from the many genera-

tions of their own kind. When we think of parental care in the animals below man, we must therefore think of care on the level of instincts rather than of reason.

All of us are familiar with the care which our own parents take of us. From earliest babyhood they provide us with food, clothing, and shelter. They care for us when we are sick, and constantly do many things to keep us comfortable, well, and happy. They have not only provided us with the materials which we need for our existence; they also have helped to teach us during our long period of youth how to get along in the world and have provided schools wherein we may learn still further to become independent, useful citizens. None of us realizes the sacrifices they have made that we may receive the best that life offers.

The types which we have chosen from the animal world to illustrate the provisions made for the young by their parents indicate clearly that as we ascend from lower to higher animals, the amount of care necessary for bringing the young to the position where they can care for themselves increases. We see that the period of infancy is longer in the higher animals than in the lower animals. In the more primitive tribes of mankind the period of infancy is much shorter than in advanced civilized society. Young Eskimos of eight or ten years of age will get into a skin boat and go out to sea on a fishing trip lasting for days. Can you imagine your father and mother allowing you to go on such a trip? The life which prim-



FIG. 168. Young opossums are carried on the mother's back with their tails curled around hers. Their balance is less uncertain than it looks.

itive people live is close to nature—they must find food and provide themselves with clothing and shelter. The Eskimo boys and girls very early learn to do these things. On the other hand, earning a living in a society like the one in which we live is a complicated matter. We must learn to read and write, and must fill ourselves with the experiences of those who have gone before us if we are to take our proper places in the world. The obligation of parents to their young in our modern civilization is to provide the opportunities for the development of their children into useful citizens, and the obligation of the children is that of making as good use of these opportunities as they are capable.

**Self-testing exercise 3.** In this problem many illustrations have been given to show you how young animals are aided by their parents.

(a) Prepare a list of all of the reasons why young plants and animals need to be helped that are suggested to you in the problem, and add to this list any other reasons that you may be able to think of.

(b) Both from what you have read and from what you may otherwise know, prepare a list of ways in which animals help their young.

(c) Why do the young of the higher animals need more parental care than those of the lower animals?

#### ADDITIONAL EXERCISES

1. Distinguish between the following kinds of fruits: pomes, berries, pepos, and drupes.

2. Make a list of the structures of seeds which aid in their distribution by the wind.

3. Make a list of the structures of seeds which aid in their distribution by animals.

4. Collect different kinds of flowers. Make drawings to show the differences in the arrangement of parts.

5. Make a list of plants that are ordinarily propagated by bulbs, tubers, rhizomes, cuttings, and runners.

## UNIT V

### HOW ARE LIVING THINGS FITTED TO THEIR SURROUNDINGS?

#### PRELIMINARY EXERCISES

1. Make a list of the forms of energy, the forces, and the materials upon which living things depend.
2. Name three animals living in the frigid and three in the tropic zones. Contrast them as to structure and mode of living.
3. List as many differences as you can between animals and plants which live in the water and those which live on the land.
4. Explain why you and a fish could not trade places.
5. Why do plants found in deserts differ so much from those found in fertile valleys?
6. Choose some animal and show how it is adapted or fitted to the surroundings in which it lives.
7. How have scientists been able to discover the changes which took place on the earth before man appeared?
8. In what ways has man disturbed the normal balance in nature?

#### THE STORY OF UNIT V

Everywhere we go, we find living things. The cold regions of the far north, the temperate middle regions, and the hot countries of the tropics have their living inhabitants. And within these regions we find deserts, high mountains, valleys, plains, oceans, fresh water ponds, rivers, and dark caves. Each of these types of homes or *habitats* has its own set of living conditions. Some offer an abundant supply of water; others, such as deserts, are known for their lack of water. Long hours of sunshine and high temperature throughout the year are characteristic of tropical lands, while the opposite

is true of the regions of the Antarctic. Living conditions at the surface of the ocean are different from those three or four miles below the surface. Living conditions on the sur-

face of the soil are different from those beneath the soil. The earth thus offers a great variety of habitats for its plants and animals; and wherever the habitat offers the necessary conditions for life, living things will be found.

You would naturally expect that the living things which dwell within the different types of habitats would differ somewhat from each other. You would not look for a fish on dry land nor for a tiger in a deep lake.

A fish is so con-

structed that it can live in water. Its body is shaped along "streamlines"; hence it can more easily glide through water. It has structures which enable it to remain afloat and force its way through the water; it can obtain oxygen and food from the water. A tiger is constructed along entirely different lines: It has legs with which to propel itself over the ground; sharp claws and teeth with which to catch its prey; and lungs for obtaining oxygen from the air. Its habits,



FIG. 169. The warm, moist tropical rain forests are dense with vegetation and animal life. Note the thick stems and broad leaves of the plants in this picture. (Underwood and Underwood photo.)

because of its structure, are different from those of the fish. If you will compare two living things dwelling in different kinds of habitats, for example, a bird and an earthworm, you will see for yourself that living things of different habitats have different characteristics. Why this is true is almost self-evident. The fish could not trade places with the tiger, nor could the tiger trade places with the fish. Each living thing is fitted to live in a certain kind of habitat and cannot exist in surroundings to which it is not fitted.

You must not get the idea from the preceding paragraph that living things are never changed or modified during the



FIG. 170. In hot, dry regions plant life is relatively scarce, and develops peculiar structures. Note the greatly thickened stems and short, bristle-like leaves of these cacti.

course of their lives so that they become better fitted to their habitat. Certain plants, for example, which normally live in temperate, moderately moist climates produce several extra layers of cells when they are grown in warm, dry climates. These layers of cells prevent the plant from losing its water by evaporation. Changes in structure such as this are responses of the individual plant to the kind of habitat in which it lives. It does not result in the production of an entirely different type of structure; it results in a modification of the structures already possessed. These changes in structure fit the individual better to its environment, but they are not passed on to its offspring. That offspring in

its turn, of course, may make a similar adaptation to its environment.

However, in this unit we are concerned with the characteristics of living things which fit them to their environment and which can be passed on to the next generation. For example, the egg cell which is produced by a fish will develop into a fish. The egg cell of a monkey will grow into a monkey. Each of these animals is fitted to live in a cer-

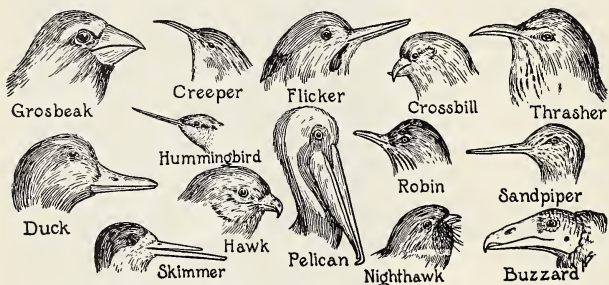


FIG. 171. The beaks of birds show great variation and adaptation. The beaks of seed-eaters (grosbeak) are short and strong; those of insect-eaters (creeper, flicker, and thrasher) are long and slender. Birds of prey (buzzard and hawk) have strong, hooked beaks for seizing and tearing flesh. The crossbill's beak is used for nut-cracking and the rapid extraction of seeds from fir cones. The duck's flat, broad beak serves as a kind of scoop. With the lower mandible of his beak the skimmer skims up small fish from near the surface of the water. The sandpiper's long, slender bill enables him to dig up animal life from the mud and sand.

tain kind of habitat. The fitness of a given kind of living thing to live in a certain kind of environment is thus passed on from generation to generation. Just how living things have become fitted to their environment and why some of the living things which exist today are better fitted than their ancestors several million years ago are matters upon which scientists disagree. All scientists agree, however, that living things are fitted to their environment and that some living things are changed in structure and form when they are placed in different kinds of habitats. In this unit we shall

consider some of the ways in which living things are fitted to their environment.

Perhaps you have wondered why there are wild elephants in Africa and none in America, or why there are whales in the ocean and none in the Great Lakes. Every part of the earth has certain plants and animals which are common to that region; in some cases they can be found nowhere else. Other regions which offer the same set of life conditions may have different forms of life. Polar bears, for example, are found within the Arctic Circle, but not within the Antarctic Circle, although the life conditions of the two regions are similar. And strangely enough, widely separated regions sometimes have identical plants and animals. The geographical distribution of plants and animals presents many interesting problems and also helps us to interpret the conditions in the past which have brought this distribution about.

Everybody has observed the unceasing competition for survival among living things. In this unit we shall consider the struggle for existence from a different angle, that is, in terms of the fitness of the living thing to the environment in which it lives. We shall see that life did not always exist in the forms we know today, and that fitness to the environment determines the types of organisms which shall survive.



FIG. 172. The llama and the camel belong to the same family of animal, yet they are found in widely separated parts of the world. (Herbert photo.)

### PROBLEM 1: HOW ARE LIVING THINGS FITTED TO LIVE IN WATER?

**STUDY SUGGESTION.** To understand how living things are fitted to their environment, it is first necessary to discover the types of conditions present in different habitats. Then we are in a position to discuss just how living things are fitted to live amid the particular conditions that surround them.

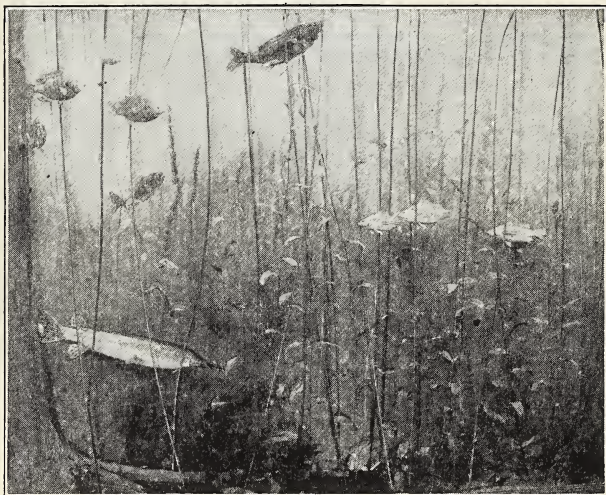


FIG. 173. Organisms that make their homes in water are adapted in many ways to securing the necessary materials for life from their surroundings. (Chicago Academy of Sciences photo.)

**What conditions are present in a water habitat?** Living in a water habitat is quite different from living on the land. We, as well as the other land animals, are accustomed to a solid surface which serves as a support to our bodies. When we place our foot on the ground and transfer our weight to that foot, we know that the earth will support us. How different it is in the water! If we go into the water, we must

either exert our energy in moving our hands or kicking our feet to remain on top, or we must lie horizontally in the water and float. Man could not live in the water permanently, because he could not swim or remain afloat forever. Soon he would become exhausted or would fall asleep, and then down he would go. As soon as he got his nose below the surface of the water, he would be unable to get oxygen, and that, of course, means death. It is evident, therefore, that an animal which lives in water must be constructed differently from man and the other land animals. To discover how living things are fitted to dwell in the water, we shall first see what living conditions are provided by the water, and then study a few plants and animals to see how they are fitted to these conditions.

Water, as you know, is a liquid. It differs from a solid, such as iron, in that bodies can move through it by simply pushing aside the particles which compose it. This can, of course, be done to a limited extent in loose soil, but as a rule, an animal moving through soil must clear away the soil in front of it in some manner before it can move its body forward. Water is similar to air in that objects can pass through it with ease; the particles of air, however, can be pushed aside much more easily than those of water. Water is also similar to air in that objects which are placed in it are totally surrounded by it and in close contact with it. Air touches every portion of the external surface of our body; water does the same for living things which live in it.



FIG. 174. Although the enormous sponge on the boy's head could not move about in search of food, it grew to this great size.

There is, however, an important difference between air and water. Water contains all the food materials necessary to maintain life; air does not. These food materials in the water may be the raw materials from which plants manufacture food, or they may be manufactured foods present in



FIG. 175. A sea-anemone, a curious, flower-like, water creature incapable of moving from place to place. (L. W. Brownell photo.)

the bodies of living things or their dead bodies. One result of this difference is seen in the many forms of sea animals which are attached to rocks or weeds or which simply float in the water. It is not necessary for these animals to move about looking for food; the food will come to them. The air, on the other hand, while it contains a few insects and birds, is not populated so

densely that an animal can get enough food from the air which is in contact with its body.

Water contains many different kinds of materials, varying, of course, in different places. Both fresh and salt water contain dissolved minerals. The amount of mineral varies from fifty to eighty parts per million in some fresh water ponds to 35,000 parts per million in the ocean. Water plants are thus surrounded with the minerals necessary to manufacture food. In addition to these dissolved minerals, there are many finely divided materials which are suspended in the water. Most of our rivers contain such quantities of these suspended materials that you can see only a few inches down into their depths. These suspended materials may be organic or inorganic; that is, they may consist of particles of once living things or of undissolved minerals. The suspended inorganic materials are of no value to the living things. The suspended organic material, however, decays

and is changed to materials which will dissolve in the water; these materials are then available for food manufacture. Water also contains the gases of the air in solution, that is, nitrogen, oxygen, and carbon dioxide. Plants living in the water are thus surrounded with all of the raw materials necessary for the manufacture of food. You would, therefore, expect the structure of plants living in water to be different from those living in air. We shall see later whether this is true.

We come now to a characteristic of water which is of utmost importance in its effect upon the structure of the living things which make water their home. Water exerts a lifting force upon objects which are placed in it. You probably have noticed this effect yourself. If you have ever rested the weight of your body on your hands when you were in the water, you have observed that you can support or lift your body much more easily than you can in air. That water does exert a lifting force can be demonstrated.



FIG. 176.

**Experiment 37. Do objects weigh as much in water as they do in air?** (a) Obtain an ordinary pair of draw scales; tie a cord around a stone as large as or larger than your fist. Weigh the stone and record its weight. Now obtain a jar large enough to allow the stone to be lowered into it. Fill the jar half full of water and lower the stone into it until it is completely submerged. Note the weight of the stone. Compare the weight of the stone in air with its weight in water. What is your conclusion?

(b) This experiment can be carried out in a more exact manner by using laboratory scales. One of the scale pans should be removed, and the scales should be balanced by a weight which is equal to the weight of the scale pan. The directions given in (a) should then be followed (Figure 176).

The experiment just performed shows that objects lose weight when submerged in water. How much weight is lost is shown by the following experiment.

**Experiment 38. How much weight is lost by an object submerged in water?** (a) Obtain a beaker or jar large enough to allow the stone (used in Experiment 37) to be lowered into it. Place the jar in a large pan. Fill the jar to the brim with water and then carefully lower the stone into the water until it is completely submerged. The stone will displace, that is, push out, some of the water in the jar. Weigh the water which overflows in the pan. (Since one cubic centimetre of water weighs one gram, the weight of the water can be determined by measuring the number of cubic centimetres of water with a graduate. The number of cubic centimetres is equal to the number of grams which the water weighs.)

(b) Compare the weight of the water displaced by the stone with the loss of weight of the stone in water. (Use the results obtained in Experiment 37.)

The experiment indicates that the lifting or buoyant force of the water is equal to the weight of the water displaced. That is, if a block of lead  $10 \times 10 \times 10$  centimetres were placed in water, it would displace 1000 cubic centimetres of water, and the lifting effect of water would be 1000 grams. Lead, however, weighs 11.3 grams per cubic centimetre; the total weight of the block would, therefore, be 11,300 grams. The water would exert a lifting force of 1000 grams; so the weight of the block in water would be 10,300 grams. The block would sink, therefore, because the lifting effect of the water would be less than the weight of the block in water. All objects, however, do not sink when placed on the surface of the water, as shown by the next experiment.

**Experiment 39. Why do some objects sink and other objects float?** (a) Obtain a piece of lead foil or heavy tin foil. Make a little boat of this material and place it on the water. Does it float or sink?

(b) Roll the material used to make the boat into a small ball and place it upon the surface of the water. Does it sink or float?

It is evident from the experiment that the shape of an object is one factor which determines whether it will float or sink. When the lead foil was in the shape of a boat, it floated because it was able to displace a quantity of water equal to its weight. When rolled into a ball, the foil sank because its small volume did not displace a quantity of water equal in weight to the ball. In other words, if the average weight of a cubic centimetre of a material is greater than the weight of a cubic centimetre of water, it will sink; if the average weight of a cubic centimetre of material is less than the weight of a cubic centimetre of water, it will float. For example, oak wood weighs .8 gram per cubic centimetre. It will, therefore, float. (Four-fifths of the material will be below the surface of the water, and one-fifth above the surface. Can you explain this?)

Since water is practically incompressible, the weight of the water displaced by an object is nearly the same at any depth. Objects will, therefore, float or sink to the bottom. Animals or plants must not weigh more than the weight of the water which they can displace, or they will sink unless they keep themselves up by swimming. Fitness to a water habitat, therefore, requires a body which can be prevented from sinking to the bottom.

Within a body of water there are also many kinds of living conditions. The surface of the water is in contact with the air and is warmed or cooled by it. Since water is a poor conductor of heat, this heat is not conducted to any great depth beneath the surface. In deep lakes the temperature



FIG. 177. In spite of the peculiar structure and bony armor of the sea horse, it is able to keep afloat by means of a gas-filled bladder; if some of the gas escapes, it sinks helplessly to the bottom. (Chicago Academy of Sciences photo.)

of the water at the bottom remains at  $4^{\circ}$  C. throughout the entire year. In the ocean the temperature of the water below 600 feet never varies. At 600 feet the temperature is always  $16^{\circ}$  C.; at 3000 feet it is always  $4.5^{\circ}$  C., and at 12,000 feet the temperature is only  $1.8^{\circ}$  C. Contrast this

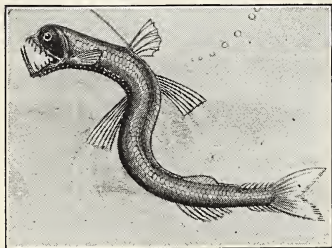


FIG. 178. This ferocious-looking dragonfish, only a foot in length, is fitted to live under deep-sea conditions: cold, darkness, and great pressure.

with land conditions. On land we must travel thousands of miles north or south of the equator in order to find the great differences in temperature which are found in water in only a few thousand feet.

Probably more important than temperature is the difference in the pressure of the water at different levels. Water is fairly heavy, one cubic foot

weighing 62.4 pounds. A column of water one foot high and one square inch in cross section weighs .434 pounds. Since the pressure of water is transmitted in every direction within it, this means that if one were to descend 100 feet into the water, the water would exert a pressure of 43.4 pounds on every square inch of his body. Native pearl divers have been able to work at a depth of sixty-five feet for a short time. To descend farther, man must use a diving suit. Living creatures have been found, however, at a depth of four miles. At this depth the pressure is about 10,000 pounds per square inch. Evidently animals living at this depth must have a structure which fits them to this particular condition.

And, finally, there is the great variation of light conditions in the water. Light is absorbed by the water; so the deeper one goes, the darker it becomes. At 300 feet the water is absolutely dark and remains so through all the miles of water

to the bottom. Since light is necessary for the growth of green plants, it is evident that no plant life is found at this depth. Indeed, experiments have shown that the great majority of water plants live in the upper sixty feet of water. How animals are fitted to live in darkness is one of the most interesting examples of adaptation.

The foregoing paragraphs have presented the conditions which are present in a water habitat. We have now to examine some of the inhabitants of the water to see how they are fitted to the conditions which are present.

**How are plants fitted to live in water?** All protoplasm is somewhat heavier than an equal volume of water. As you have already learned, this means that it will tend to sink to the bottom. Since this is true, how then can living things float? If they were composed of protoplasm alone, they could not. Examination of these floating organisms shows that many of them store fats and oils in their bodies. These materials are lighter than water—as you can determine for yourself if you will put a little butter or olive oil in a glass of water. The storage of these materials by a living thing cuts down the average weight of the body to the point where it weighs approximately the same as the water it displaces; hence, the body floats. Furthermore, gases given off during the process of digestion and assimilation of food are distributed throughout the body of the living thing. These help to reduce its average weight below that of an equal volume of water.

Some living things have a sort of gelatinous membrane which surrounds the body and increases its bulk so that it can displace more water. Others have extended parts of their body to provide more surface area. Still others, like some of the fishes, store gases in a bladder, which helps them to float in the same manner as the water-wings used by beginning swimmers. In general, the methods above, or combinations of these methods, are found in all living things which make water their home.

Suppose we turn first to a consideration of the plants which are found in water. Plants living in water are called *hydrophytes*. The surface water of the sea is fairly swarming with billions of microscopic plants. An analysis of one quart of water in Kiel Bay, Germany, showed the presence of 6,336,000 diatoms (Figure 179). It is these diatoms and other plants like them that manufacture most of the food required for all of the creatures of the sea. They supply the food for microscopic animals which are in turn devoured by

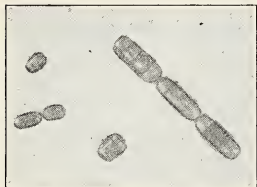


FIG. 179. Barrel diatoms, highly magnified. (Field Museum photo.)

slightly larger animals; these are eaten by larger animals, and so on. These plants float easily because of their microscopic size; hence, they are well adapted to a life in the water.

In addition to the tiny green plants there are countless other green plants which live in the open waters. They are fitted to the water habitat in certain definite ways. Many of them have neither roots which penetrate into the soil nor strong stems to support their weight. They therefore must be adapted to floating. Figure 180 shows one of the lilies which grows in the tropics. Note the large leaves which are turned up at the sides. These leaves not only support the weight of the plant, but large birds may frequently be found using the leaves as a resting-place. The water hyacinth, shown in Figure 181, has a different type of adaptation for floating. Notice the leaves which are swollen into the form of a bladder.

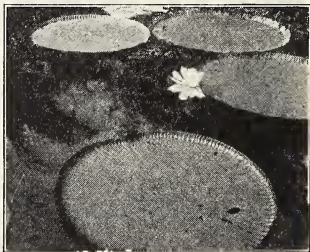


FIG. 180. The giant water-lily of the Amazon River region. (Field Museum photo.)

These bladder-like structures are filled with a spongy material which contains air. They thus serve as a buoy for the plant.

In addition to devices for flotation, water plants have other characteristics which fit them to a water habitat. Examination of their roots shows that the outer layers of the roots do not thicken as they do in land plants; hence, water and minerals may be absorbed by the entire length of the root. Some water plants do not have roots at all; they absorb materials directly through their leaves. This is possible because the leaves of water plants have but a very thin epidermis as compared to land plants. A thick epidermis is not needed by water plants, because they are not in danger of losing water by evaporation. The leaves of water plants are usually much divided; thus they provide more surface. This is necessary because the water absorbs much of the light, and greater surface is needed in order to catch what little light there is. Note Figure 182 and observe the difference between the leaves which are under water and those which are above the surface.

Another characteristic of water plants is observed in the weakness of the stems. The water buoys the plant up; so strong stems are not needed for support. Many more examples of how plants are fitted to a water habitat could be given. You will find it interesting to discover some of the ways for yourself. A comparison of these plants with soil plants will help you locate these adaptations.

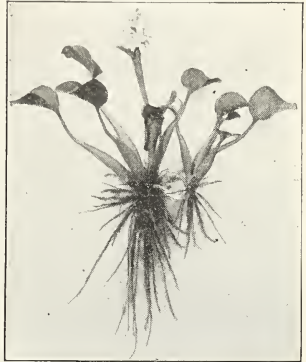


FIG. 181. A water hyacinth. (Field Museum photo.)

**SUGGESTED ACTIVITY.** If you can visit a pond or stream, find different kinds of water plants and determine what structures they have that enable them to float.

**How are animals fitted to live in water?** Now let us turn to animals to see how some of them are fitted to a water

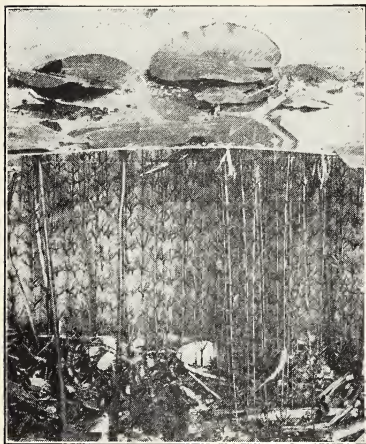


FIG. 182. Notice the many finely divided leaves covering the slender stems of the plants under water. (Chicago Academy of Sciences photo.)

habitat. We shall first consider the jellyfish (Figure 183). It, as the picture shows, is adapted by its structure to a life of floating and drifting. As a matter of fact, the animal is practically all water; it has no skeleton of any kind and collapses almost into nothingness if brought out on dry land. Yet this animal sometimes grows quite large. Louis Agassiz, a great American biologist, found one in which the bell was seven and one-half feet across and the tentacles more than

one hundred twenty feet in length. An animal of this size could not exist on the earth if it were dependent upon the food which was brought to it or which came within its reach. The development of such an animal could be possible only in a water habitat. Here, every part of the surface of the animal comes in contact with the food-bearing water.

Of the active creatures of the sea the fish is most successfully fitted to rapid locomotion. It does not depend entirely upon its ability to float to prevent it from sinking; it depends

upon the swimming movements of its body. Its body is of the familiar "streamline" form, narrowed toward each end, but sloping more gradually near the rear end. The strong tail fin provides the greater part of its driving power. As its head is pushed against the water, the water is forced aside, and then returns to its place. As it returns, it presses against the sloping rearward part of the body and pushes the fish forward. Most of the force required to push aside the water is thus not lost, because the water returns the force when it flows back into place.

Some fish have an enclosed gas bladder which they can increase or decrease in size and thus regulate their buoyancy according to the water in which they are swimming. This relieves them of the necessity of using so much energy to remain afloat. Like other animals which make water their home, fish are equipped with gills which enable them to obtain the oxygen that is dissolved in the water.

**SUGGESTED ACTIVITY.** Visit a pond or stream and with the aid of a dip net capture some small water animals. Bring them to the laboratory and study them to determine how they are adapted to a water habitat.

Deep down in the sea, where absolute darkness prevails, where the pressure is thousands of pounds per square inch, and where the temperature is near the freezing point all

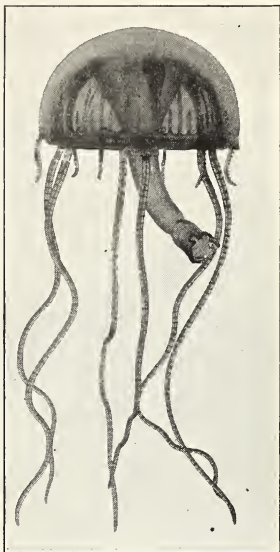


FIG. 183. The jellyfish uses its tentacles to draw food to its mouth, which is the tubular projection beneath its body. (Roy Pinney photo.)

year round, live creatures which are strange to behold. Unlike the fish of the upper levels, these creatures are dependent for food upon the dead bodies of plants and animals which sink slowly through the water. Since food is available only at infrequent intervals, you would not expect to find in this environment fish of any great size. Such is the case; for these deep-sea fish are rarely over a foot in length.

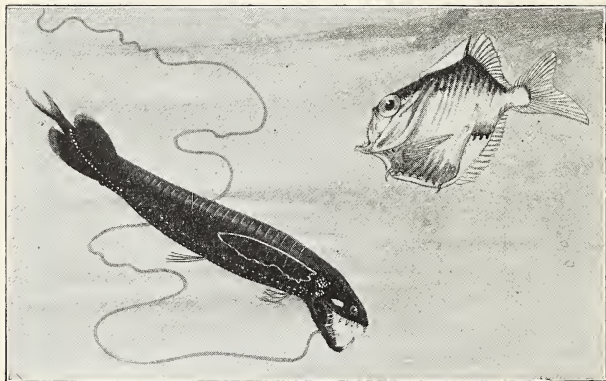


FIG. 184. Two denizens of the deep: a large-eyed hatchetfish and a dragonfish with large jaws, sharp teeth, and rows of phosphorescent organs along its sides. Man has not yet been able to discover the value to the fish of the extremely long *barbel* attached to its chin.

These inhabitants of the deepest waters differ from those of the upper waters in two noticeable ways (Figure 184). Most of them are equipped with jaws which are entirely out of proportion to the rest of their body. These jaws enable them to grasp the large bodies which sink slowly from above. More interesting than the jaws, however, are their phosphorescent organs. Scientists do not know how or why these have developed so greatly in the deep-sea animals. It is probable, however, that they are of definite advantage to their possessors. Some of these organs are like the head

lights on an automobile and enable the animal to find its way about and discover food. Others occur in strange patterns over the animal's body and apparently serve as marks of recognition to others of the same species. Still others are thought to act as lures, as in some of the deep-sea anglers. These animals are blind, and the phosphorescent organs are simply bait to lure inquisitive fishes within reach.

As would be expected, the eyes of deep-sea fish are usually very large, so that they may catch the few rays of light given off by themselves and other living inhabitants of the deep. In some species, however, the eyes have degenerated, and the animal is blind. These animals have usually developed the organs of touch to a much higher degree than their surface relatives.

You have probably heard that deep-sea fish explode when brought to the surface. This is true for those fish which have enclosed gas bladders, particularly when they are brought to the surface rapidly. You may have had an experience somewhat similar to this if you have ascended a high mountain. The pressure of the gases in your blood is the same as that of the air around you. If you ascend a high mountain quickly, the pressure of the gases in the blood does not have time to become adjusted to the lower pressure outside. The pressure of the gases in the blood is often so much greater than the air pressure on the outside that it forces the blood out of the blood vessels, resulting in a nose bleed. If one, however, remains in a region of low air pressure for a time, the pressure inside of the body gradually adjusts itself to that outside of the body, and no discomfort is felt. Deep-sea fish suffer no discomfort from the great pressure, because the pressure is the same inside of their bodies. Many of the deep-sea fish do not have enclosed gas bladders and can, therefore, be brought to the surface without exploding. Most of them are dead when they reach the surface, but this is thought to be due to the great difference in temperature, rather than to the difference in pressure.

Alligators, members of the great group of reptiles, are also adapted to a water habitat. Biologists tell us that the reptiles were the first animals to be successful in colonizing the dry land. The alligator is thus a descendant of a land-living animal. It has, however, returned to the water to live. It is well adapted to live in this environment. The armor of scales upon its back protects it from its enemies and makes the animal almost invisible as it lies in the water or on a grassy bank. Only its eyes and nostrils are out of the water

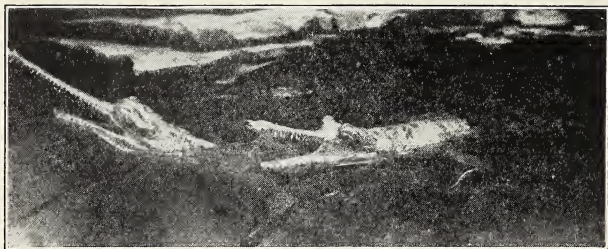


FIG. 185. Crocodiles, like alligators, have structures which adapt them to their water habitat. (Herbert photo.)

as it swims or floats in the water. Its tail is an excellent propeller, enabling it to swim faster than a man can paddle a canoe. It can keep its mouth open under water without allowing water to enter its lungs, because it is provided with membranes on the inside of its mouth which can close the passage to the lungs. It is, therefore, able to seize other animals and hold them below the surface until they drown. The hippopotamus and the whale are also descended from land animals, but they have returned to the water to live.

The few examples which have been given show the general types of fitness to a water habitat. The story, however, is just begun. You will find it interesting to observe or read about water-bugs, frogs, crayfish, whales, seals, beavers, hippopotami, and other animals living in water to discover how they are adapted to their environment.

**Self-testing exercise 1.** Turn to the self-testing exercise for Problem 2 on page 222. Make a table like the one shown there, and fill out that part of the table which is concerned with a water habitat. Save your table to be completed in Self-testing Exercise 2.

## PROBLEM 2: HOW ARE LIVING THINGS FITTED TO LIVE ON LAND?

**STUDY SUGGESTION.** As you read the material presented in this problem, try to find the special kinds of conditions present in a land habitat. Then, before you study about the types of adaptations, make a list of those types of adaptation that are necessary. Compare your list with those given in the examples.

If it were possible for man to see all those events which have happened in the history of the world, he would witness strange sights indeed. If he went back far enough in the history of the earth, he would find a time when the land surface was barren of living inhabitants. For millions and millions of years before the first land form was developed, life existed in the water. Before the dry land could be colonized, living things had to develop a structure that would make it possible for them to exist under the conditions which are present in this type of habitat.

We have already learned about the conditions present in a water habitat and the structures which fit living things to this environment. Now let us consider the conditions present in a land habitat, and the types of structure necessary for living things to make their home upon the soil.

**What conditions are present in a land habitat?** A land habitat differs from a water habitat in several important particulars. In the first place, a living thing is surrounded by air instead of by water. Since air has different properties from water, a new set of conditions prevails. Let us first see what the properties of air are.

Air, as you know, is a mixture of certain gases. When damp objects or water are placed in air, the water evaporates; that is, it changes to a gas and passes into the air. Except

on very humid days or during a rain, the water is thus constantly evaporating from moist surfaces. This, as you shall see, has an important effect upon the structure of living things. Practically every day there is a marked change in the temper-

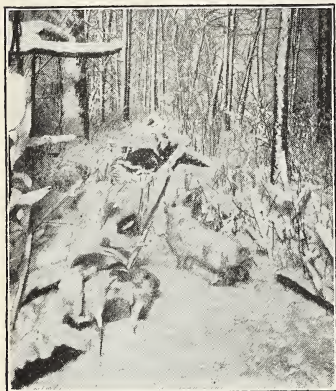


FIG. 186. When you imagine what this bit of woodland looks like in spring and summer, you can realize how living things must adapt themselves to great extremes of heat and cold, moisture and dryness. Note also that these rabbits are almost invisible to an enemy.

ature of the air. During the day, while the sun is shining, the temperature rises, and during the night the temperature falls. There is also a marked difference in temperatures at different seasons of the year. These changes in temperature are much greater than those which take place in water. Let us next consider the lifting effect of air. While it is true that air buoys up objects in the same manner as water, the lifting effect is very small as compared with water. This is true because air weighs very little (it takes about twelve

cubic feet of air to weigh a pound); and since the lifting effect is determined by the weight of the air displaced, most objects are buoyed up but little. They weigh much more than the air they displace. Finally, as you know, air does not contain all the raw materials needed for the manufacture of foods. A comparison of water and air as surrounding mediums thus indicates important differences in the types of conditions presented by these two environments.

The other important feature of a land habitat is the soil. The soil also has certain properties which are unlike those of water. The soil presents a more or less solid surface upon

which the animal rests. Locomotion is accomplished by pushing against the soil with the part of the body in contact with it. The entire weight of the body must therefore be supported, and sufficient force must be exerted to move this weight. Like the water, the soil is a source of raw materials for the plant, with the important difference that these raw materials are not brought to the plant as they are in water; the plant must go after them. Soils, of course, differ in composition, in their ability to hold water, and in many other respects. These differences and their effect upon plant life we shall consider in Unit VII.

**How are land plants adapted to their surroundings?** And now

let us see how plants are fitted to live on land. We find one noticeable characteristic of land plants in the structures which prevent the loss of water from their tissues. Evaporation of water is constantly going on from plants. It has been estimated that a field of corn gives off enough water in a single growing season to cover the land upon which the corn is grown to a depth of seven inches. Some loss of water cannot be prevented, but if more water is lost than is taken in, the plant will wilt and die.

If you examine the epidermis of a leaf you will note the presence of a fatty material called *cutin*. This cutin serves as a kind of water-proofing for the leaf and limits the loss of water from leaves to that which comes through the stomata. Cutin is present in most plants living in dry climates and also to some extent in plants of the moist temperate regions.



FIG. 187. An oak leaf covered with hairs which help prevent the rapid loss of moisture.

Submerged water plants, on the other hand, do not possess cutin. (You will recall that in many water plants the epidermis is very thin, and water and other materials may be absorbed by all parts of the leaf.) Many leaves, such as those of



FIG. 188. Several varieties of tropical orchids have long, dangling air roots covered with absorbent tissues to take up water quickly from the air.

the agave (one of the century plants), are covered with a layer of wax; others, such as those of the creosote bush, a desert plant, with resin. These materials make the epidermis watertight (except for the stomata) and also reduce the amount of heating from the sun. Still others, such as the mullein and the cineraria, are covered with hairs which probably reduce the amount of surface exposed to the air (Figure 187).

Along with the devices used to prevent evaporation, there are certain structures of the roots which assist the plant to obtain more water. The roots of land plants are so built that they can force their way through closely packed soil in all directions and thus come in contact with water. The absorbing area is also greatly increased by the multitude of root hairs. These root hairs increase the absorbing surface of a plant, such as barley, at least twelve times. The extensive root system of plants also anchors the plants in the ground and prevents strong winds from destroying them.

Since air cannot support the weight of our common land plants, it is evident that stems must be developed which will hold the leaves up into the light. This structural feature is accomplished by the fibrous cells of the *bast* (the phloem

portion of a fibrovascular bundle) and the woody portion of a fibrovascular bundle, the xylem (Figure 108, page 124). These cells dovetail with each other and give strength to the stem. That these fibers are extremely resistant to stress and strain is shown by the fact that bast fibers of certain kinds of plants, such as hemp and jute, are used to make rope and cable.

We have already noted that plants contain *tracheids* and sieve tubes, through which water and food are conducted. The transportation system of land plants is much better developed than that of the water plants. This, of course, is necessary because the raw materials for food manufacture in land plants come from two widely separated sources, the air and the soil. An adequate system of distribution is thus required to bring these materials together in the leaf of the land plant.

Finally, land plants need a method of reproduction which will protect the young embryos from extremes of dryness, heat, and cold. This needed protection for the young embryos has been provided through the development of the seed. The extent of this protection has been demonstrated experimentally. Some seeds can withstand a temperature of 100° C. (the temperature of boiling water) for several hours. Some seeds have been germinated after having been kept at a temperature of 250° C. for several days.

Land plants are thus quite different in structure from water plants. Each is fitted to live under a certain set of conditions. In general, neither could trade places with the other and continue to live.

**SUGGESTED ACTIVITY.** Collect some water plants and some plants which live on the land. Compare them to note their likenesses and differences.

The preceding paragraphs have presented a general discussion of the fitness of plants to a land habitat. Now let us consider some examples of adaptation to particular types of land habitats. In general, land habitats may be

divided into two classes, depending upon the amount of water available. At the opposite extreme from the water plants, or hydrophytes, we have the *xerophytes*, living in deserts or other regions where water is scarce. Midway



FIG. 189. The yucca tree, common to the desert regions of southwestern United States and Mexico, has long, pointed leaves and thick stems. (Photo by G. D. Fuller.)

between the hydrophytes and xerophytes are the *mesophytes*, living in regions where water is more or less abundant. To illustrate adaptation to environment, let us examine the characteristics of the xerophytes. What would you expect to find?

Figures 189 and 190 show some of the characteristic plants of regions where little water is available. What is the most notable difference between these plants and the hydrophytes and mesophytes? Observe the leaves and stems. Note how thick

they are. Small, thick leaves do not expose so much surface as do large, thin leaves of the same volume. This characteristic, therefore, shows adaptation to a hot, dry climate where evaporation is rapid.

In most xerophytes the thickness of the leaves serves still another purpose. The cells in the epidermis and in the interior are capable of holding water, and they thus enable the plant to store water through long periods of drought. The retention of water by the cactus is so great that the plant may be dried under pressure for weeks, and still it will keep on growing. Tree cacti may hold several hundred gallons of liquid. Travelers in the desert often cut them open to obtain this liquid when their supply is running low. In Mexico there is a plant called the resurrection plant which can be dried

for years, and will then freshen up in a few hours when placed in water. Another feature of the xerophytes is their extensive root system. In some regions water can be obtained only at great depth in the soil. The mesquite bush is said to put down a root to a depth of sixty feet. Indeed, the root system is often better developed than the rest of the plant. One of the morning-glories growing in dry regions sends down a root from twenty to thirty feet, while the part of the plant above the surface is only a foot high.



FIG. 190. To prevent loss of moisture the leaves of the giant cactus have practically disappeared, and the stems have taken over the food-making function of the leaves.

As you would expect, the mesophytes present structures which are intermediate between the xerophytes and the hydrophytes. Their leaves may be large, but they are provided with cutin to decrease the rate of evaporation. Their root system is more extensive than those of the hydrophytes and less well developed than those of the xerophytes.

**How are land animals fitted to their surroundings?** And now let us turn from plants to a consideration of the fitness of animals to a land habitat. Animals, like plants, first developed in the water and later colonized the land. Water animals, as we have seen, are adapted to getting the oxygen that is dissolved in water. As we have already seen, fitness to a water habitat requires the ability to obtain the oxygen

dissolved in water and the ability to keep from sinking to the bottom. Manifestly, the structures which adapt animals for these purposes do not fit an animal to live on land.

A land animal must have structures which enable it to obtain oxygen from the air. The skin can no longer be used for this purpose because exposure to the sun and air make necessary a thickening of the skin and the production of hair and other structures designed to prevent the drying up of the body tissues. Structures which will keep water and air from passing out will also keep these materials from passing

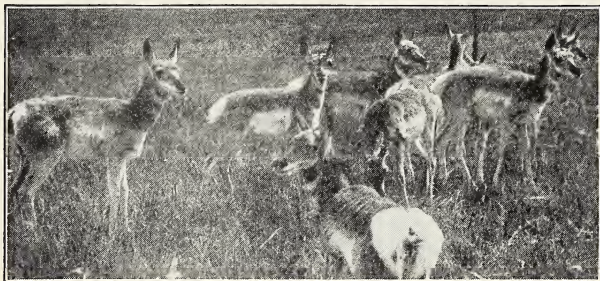


FIG. 191. The antelope has little means of self-defense, but it is capable of tremendous speed. (L. W. Brownell photo.)

in. A new method of locomotion was also necessary for land animals. In most land animals these limbs are underneath the body rather than on the sides. Furthermore, these limbs are fairly long in order to raise the body above the ground far enough to secure reasonably easy locomotion. The antelope with its long legs, for example, is capable of moving at a speed of sixty miles an hour. Along with the changes just mentioned came changes in the disposal of the eggs to insure their safety. Safe disposal of eggs is much more difficult on land than in the water because of exposure to drought and changes in temperature.

Up to this point we have been concerned with the general types of adaptation to land habitats. And now we come to

some of the more specific adaptations of animals. Here, one is confronted with so many examples that it is difficult to choose which ones to present, for every animal is a bundle of adaptations. If it were not, it could not exist.

As one example, let us take the types of fitness displayed by the feet and claws of animals (Figure 192). The feet of some animals, for example, the squirrel, raccoon, opossum, leopard, and cat, are adapted for climbing. The mole, gopher, and burrowing beetle have feet fitted for digging through the soil. The feet of some birds are fitted for catching other animals; others, like those of the chicken, are fitted for scratching in the dirt; still others, like those of the duck, are adapted for swimming. Mountain goats and polar bears are fitted for walking on smooth surfaces such as ice and rocks. If you will examine the feet and claws of other animals, you will find that they fit the animal for living in certain kinds of habitats and for doing certain things.

Even the tails of animals help to adjust them to their environment. A horse uses its tail to brush away the flies and other insects; certain monkeys use their tails to swing from the branches of trees; the tail of the squirrel maintains the balance of the animal when it jumps; the beaver's tail serves as a rudder in swimming; the rabbit uses its tail as a signal to others of its kind; the tail of the kangaroo acts as a prop for the animal when it rests on its hind legs, while the porcupine and alligator use their tails as powerful clubs to protect



FIG. 192. The star mole, so called because his nose is fringed with star-like points, has large feet and claws for digging tunnels in the ground. (Lynwood M. Chace photo.)

themselves from their enemies. In similar manner we might examine the noses, ears, and other parts of animals. Here also we would find evidences of fitness to the environment.



FIG. 193. Porcupine. Observe his formidable defense mechanism.

**SUGGESTED ACTIVITY.** Make a study of the eyes of animals, such as the cat, dog, deep-sea fish, owl, fly, and spider. Explain how these different kinds of eyes are adapted to different environments.

One of the interesting angles of fitness is that concerned with the structures which protect animals from the physical features of the environment and from their enemies. Mention has already been made of protection from dryness and from high tem-

peratures; so let us pass on to those structures which protect the animal from its enemies.

The porcupine is an interesting animal to observe, but not a pleasant one to caress. When attacked, its short spines rise. This is a warning to go no further. The quills detach at a touch and enter the body of the attacking animal. They are so constructed that they work their way inward and cannot be removed. The turtle and the armadillo are protected with coats of armor. The snail and some of its relatives withdraw within their shell and defy the attacking animal to come and get them. The bee and wasp, as many of you know, have



FIG. 194. The larva of the Cecropia moth is well protected with sharp spines. (Geo. T. Hillman photo.)

stingers which are quite effective in discouraging unwelcome attentions. Some of the fishes have structures like storage batteries which enable them to kill their enemies by electric shock. Certain snakes, spiders, and lizards have fangs which can inject poisons into the body of the victim and paralyze or kill it. The skunk has an effective weapon of defense in the fluid that it liberates. The cuttlefish emits a dark, inky liquid when attacked, which serves the same purpose as the smoke screen used to conceal battleships in time of war. It is interesting to note that some of the deep-sea relatives of this animal give off a luminous cloud which effectually conceals them in these lightless areas. Many caterpillars are covered with unpleasant liquids which are extremely distasteful to chickens and other animals eating insects and their larvæ. Experiments have shown that young chickens will try them once or twice, but after that they will leave them severely alone. Scattered through these pages you will find many more examples of protective structures.

It is impossible in this book to mention more than a few of the many kinds of fitness displayed by animals. While it is true that, in general, all animals are fitted to their environment, it is not necessarily true of all of the structures possessed by animals. Many of the structures present are *non-adaptive*; that is, they apparently serve no useful purpose in the animal. So long as they do not hinder the animal, they may remain a part of his structure. But if structures do develop which are harmful to a species of animal, this

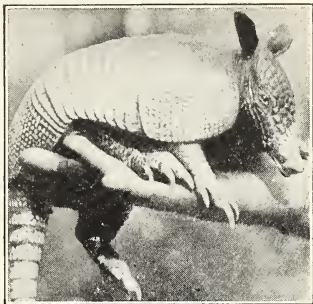


FIG. 195. Some species of the armadillo curl up into a ball when they are attacked, thus presenting armor on all sides. (Herbert photo.)

species, as we shall see later, does not survive the struggle for existence.

**SUGGESTED ACTIVITY.** Observe and read about animals to discover the structures which protect them from their enemies. Look especially for strange and unusual structures, and try to determine whether they are of any definite value to the animal possessing them.

**SUGGESTED ACTIVITY.** Make a study of birds to discover how they are fitted to flying.

**Self-testing exercise 2.** Make a table like the one below and fill it in from your study of Problems 1 and 2.

A COMPARISON OF WATER AND LAND HABITATS AND THEIR INHABITANTS

| HABITAT | PHYSICAL CONDITIONS    | TYPES OF STRUCTURES<br>(Plants) | TYPES OF STRUCTURES<br>(Animals)  |
|---------|------------------------|---------------------------------|-----------------------------------|
| Water   | Liquid                 | Bladder for flotation, etc.     | Tails and fins for movement, etc. |
|         | Buoys up objects, etc. |                                 |                                   |
| Land    |                        |                                 |                                   |

### PROBLEM 3: HOW ARE ORGANISMS FITTED TO THEIR ENVIRONMENT BY EXTERNAL APPEARANCE?

**STUDY SUGGESTION.** It is possible in this problem to describe only a few of the many types of fitness which actually exist. You will find it profitable to recall the appearance of the wild animals which you have seen and then, using as a guide the examples given here, to discover how these animals are fitted by their external appearance to their surroundings.

To many wild animals life is a series of hairbreadth escapes from being killed for food by some other animal. Every wild animal has its enemies. During times of war man also has enemies who seek to kill him. A good many years ago our soldiers were clad in brilliant uniforms; in recent times, however, man has found it advantageous to make

himself as invisible as he can to the enemy. For this reason, during the World War soldiers were clad in olive-drab uniforms. This color harmonizes and fuses with the colors of grass, trees, and dirt. A similar transformation was effected in the ships. They were striped in irregular lines which made it difficult for the enemy to determine the exact size of the ship and its direction of travel. The ships were said to be *camouflaged*. The art of camouflage is that of making an object appear other than it really is.

Man, however, as compared with many animals is but a beginner in the art of camouflage. For a lesson in disguise, look closely at the walking stick shown in Figure 196 on this page.

Not only does this animal resemble the twigs in shape, but it also resembles the twig or the leaf in its color. The wings of the dead-leaf butterfly resemble a dead leaf almost perfectly in details of color, veins, petioles, and even worm holes. Unless you look very closely, you will find it almost impossible to locate them.

Now it must not be thought that these animals proceeded on the same basis as man. Man started out with the idea of making his soldiers and ships as invisible as possible; he experimented with different colors and patterns until he found the best combinations. The lower animals, of course, cannot think and plan in this manner. They do not know that they are inconspicuous, and they certainly have not in any way planned to become almost invisible. The fact remains, however, that there are many kinds of animals

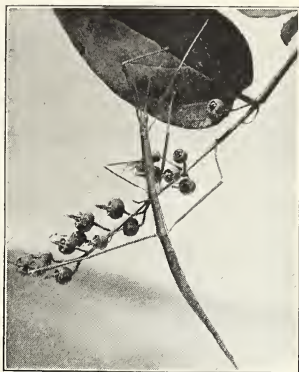


FIG. 196. A walking stick. (L. W. Brownell photo.)

which resemble in form and color the objects in their environment. By reason of this resemblance they are so inconspicuous that they may be overlooked by many of their enemies. Just how this resemblance was brought about is

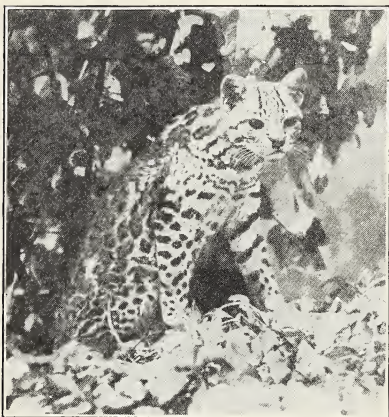


FIG. 197. The markings of the Mexican leopard blend in with the spots of light and dark in the foliage. (Herbert photo.)

difficult to say. Scientists themselves differ in their explanation. We shall learn more about it in Problem 4. Here we are concerned with the fact of *protective coloration* and form.

The examples of adaptation to the environment through protective coloration are almost unlimited. Through extended observation of animals in different habitats it has been possible to determine

more or less definitely the type of coloration that will be found in a given environment. In fact, the habitat of an animal may usually be inferred from the general appearance of the animal.

In the desert, animals are usually dun or gray in color, as exhibited by the gazelle, the camel, and the lion. It is interesting to note that gazelles of the same species found in lava regions are usually gray in color, while those found in sandy regions are dun or white. Plains-dwelling animals, such as the antelope and coyote, are very likely to be the color of dry grass. The inhabitants of the jungle, such as the tiger and the zebra, are usually striped. The alternate stripes of dark and light colors resemble very closely the bars

of sunlight and shadow in the tall jungle grasses. Forest animals like the leopard (Figure 279), jaguar, boa constrictor, and fallow deer are usually dappled, giving the effect of the splashes of light which come through the leaves. Forest insects, such as the katydid, walking stick, and others, are usually green. The wings of the katydid are veined in such a way that to a marked extent they resemble leaves. Along the white, sandy stretches of the seashore practically all of the animals are of a whitish or an inconspicuous ground color.



FIG. 198. The dark upper surface of a frog, shading to a very light lower surface, helps it to escape detection from enemies both above and below the water. (L. W. Brownell photo.)

If you will observe most animals, you will find that the upper surface of the body shades off gradually to a lighter color, which counteracts the shadow of the body. This makes the lower part of the animal appear to be the same shade as the rest of the body. The sloth, however, which travels hanging beneath the boughs of trees, is lighter on its back than on its under side. Brook fishes are usually olive-colored on their upper surface, and light-colored beneath. Thus, viewed from above they are difficult to detect against the bottom of the stream. From below, their light under side against the light also renders them less conspicuous. Enough examples have been given to draw the general conclusion that many animals have colors and color patterns which fuse with their usual environment and make them almost indistinguishable from their immediate surroundings.

Some animals can even change their color to some extent to harmonize with their surroundings. The most common example is the chameleon. This animal is ordinarily bronze-

hued, but it can change its color through olive to pale green or turquoise blue. Many people believe that the animal will change to the color of any object on which it is placed, but

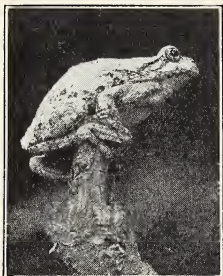


FIG. 199. The tree frog shows further adaptation to its environment by the suction discs on its toes to aid it in climbing. (L. W. Brownell photo.)

this is untrue. The change in color is due to the movement of the pigment, or color, cells up and down in the skin of the animal. It is thought that this movement is due to changes in the amount of heat and light absorbed or reflected by the material upon which the animal rests. Whatever the factors are that bring about these changes, it is certain that they are not due to any conscious activity on the part of the animal. The tree frog (Figure 199) is another animal that changes its color; it is usually a grayish color on a branch and green when transferred to a green leaf.

Some animals change their color from season to season. In summer the arctic fox, arctic hare, weasel, and lemming are of a color which fuses with the browns of leafy soil. In



FIG. 200. The ptarmigan, a species of grouse, has both a winter and a summer plumage.

the winter, however, they turn white and thus harmonize with the snow-covered ground. Experiments with lemmings show that if the animal is kept in a warm room in the winter,

it will not change to white. If exposed to the cold, however, it will change its color. Change in color, therefore, is brought about by the conditions to which animals are exposed.

But there are some animals which display colors and color patterns producing just the opposite effect upon their visibility; that is, they are made more conspicuous. The wasps, bees, butterflies, and some of the snakes



FIG. 201. The Gila monster, a large poisonous lizard found in arid regions of the United States, advertises its presence by its conspicuous coloring of orange and black. (Chicago Academy of Sciences photo.)

display brilliant reds and yellows. These colors advertise the presence of the animal, rather than conceal it. Many of the animals possessing conspicuous coloration are provided with special means of defense such as poison fangs, stingers, and body secretions which make the animal very unpalatable for food. Experiments show that when hungry animals are given conspicuously colored, unpalatable caterpillars to eat, they may try them once or twice, but they learn to recognize them, the color aiding them to learn this lesson. Most preying animals recognize and avoid those animals which are conspicuously colored. If they are recognized in time, those species are almost immune from attack. *Warning coloration*, as it is called, is thus of considerable advantage to its possessor. Of course, it may not protect a given individual of a species, because other animals have to learn to avoid the species by one or two unpleasant experiences with them.

One of the most interesting features of color and pattern formation is known as *mimicry*. Here an animal apparently has copied another animal. Some species which have no natural means of defense so closely resemble others which do have means of defense that the two kinds can hardly be distinguished from each other. The robber fly, which has no

defense, mimics the bumblebee. Another example of mimicry is exhibited by the viceroy butterfly, which resembles the monarch butterfly (Figure 284). The larva of the monarch butterfly feeds upon milk-

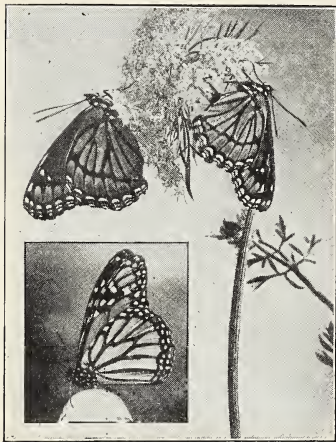


FIG. 202. Can you distinguish the viceroy from the monarch butterfly? The viceroy butterflies are on the flower, and the monarch is beneath them. (L. W. Brownell and Lynwood M. Chace photos.)

weeds, and it is supposed that the disagreeable taste of this plant gives the butterfly a disagreeable taste. Whatever the reason may be, this butterfly is inedible. The viceroy butterfly, however, is edible. Its resemblance to the monarch butterfly is probably very advantageous in protecting it from animals which have had unpleasant experiences with the monarch butterfly.

The examples given above establish the fact that some animals do resemble other animals, and that this resemblance is of advantage if the animal resembled is conspicuously

colored and has powerful weapons of defense. How this resemblance was brought about is an entirely different story; many explanations have been given, but as yet scientists do not all agree.

**SUGGESTED ACTIVITY.** Make a collection of animal pictures and, if you can find some, of animals themselves which show protective coloration.

**SUGGESTED ACTIVITY.** Make a collection of animals and of animal pictures which show aggressive coloration.

**Self-testing exercise 3.** State as many reasons as you can for believing that the external appearance of animals fits them to survive in their environment.

#### PROBLEM 4: WHAT LIVING THINGS SURVIVE THE STRUGGLE FOR EXISTENCE?

**STUDY SUGGESTION.** Read through the material presented in this problem to get a general idea of the whole. Then read the self-testing exercise on page 238 and study the problem. Keep this exercise in mind as you study.

Earlier in this unit we used the phrase "struggle for existence" to suggest that living things must compete for room, water, food, and other necessities of life. Problem 5 enlarges on the relationship between living things and the balance of life which exists as a result of this relationship. In this unit we have been concerned with the types of structure which fit living things to the environment in which they live. In the struggle which

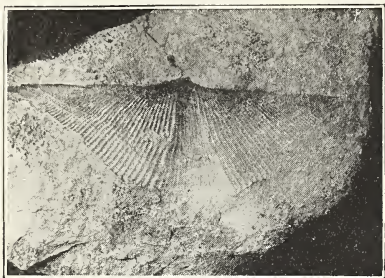


FIG. 203. A mold of a Brachiopod, an animal with a shell composed of two valves connected by a hinge, like that of an oyster. There are few living forms of it now. (Walker Museum photo.)

takes place those species that are best fitted to the environment are the ones that succeed. We shall therefore consider in this problem the part that adaptation plays in producing the forms of life which now exist upon the earth.

**How have we learned of life in prehistoric times?** To secure data for our study we must go to the *paleontologist*, that is, to the scientist who studies ancient life. Through his efforts it has been possible to build up a fairly complete picture of life through millions of years of the earth's history. The paleontologist obtains his evidence and bridges the gap between the present and the past through a study of *fossils*.

Fossils are of many kinds: They may be the actual remains of plants or animals which have existed in the past; they may be parts of the animals which have turned to stone; they may be imprints left by some living thing; or they may

be molds or casts of once living things.



FIG. 204. At the left is a cast of a marine snail; at the right is a spiral shell like the one around which the cast was formed. (Walker Museum, photo.)

How these fossils were formed is an interesting story. If an animal or plant happened to die in some place where its body was immediately surrounded by a material which would preserve it, the body of the animal would be little changed by decomposition. This has actually happened in many cases. In the frozen north of Siberia bodies of the great hairy mammoth (animals resembling the elephant) have been found

frozen in the ice. When these animals are removed from the ice and thawed out, the flesh is in such perfect condition that dogs will eat it. Many species of extinct insects have been found in amber, a solid material formed by resin. It is assumed that the insects were caught in the sticky resin, which later solidified. Since they were protected from the bacteria and oxygen, their bodies were not decomposed.

Materials are said to be petrified when each particle of the organic matter has been replaced by mineral matter. In some cases the replacement has been so perfect that sections of tissues preserved in this manner show all of the finer details of structure. At times, animals or plants have been buried in the mud long enough to impress their shape upon this plastic material. Later the organism has decayed

and dissolved away, and its place has been taken by mineral matter. When this happens, a cast of the body remains, showing its size and external appearance (Figure 204). Imprints such as shown in Figure 205 may also be preserved.

An examination of rocks shows that fossils are found only in certain kinds of rock. They are not found in rocks which were formerly in a molten condition (lava); or those like granite, which, although they were not originally molten, were later heated to a point where any fossils would be destroyed. Fossils, in general, are found only in the *sedimentary* rocks, that is, those formed by the settling of sand, clay, mud, or lime particles in water. These particles were carried by streams into large bodies of water where they slowly settled to the bottom. As the pressure of succeeding layers was added, the sediment



FIG. 205. An imprint of a fern leaf in a rock. (Walker Museum, photo.)

gradually hardened and became stone. Animals that live in the water must, of course, sometime die. Their bodies sink to the bottom, where they are covered with sediment, and many of them become fossilized. Land animals are occasionally washed into the sea or sink in quicksands or mire in the soft mud, and they, too, are on their way to becoming fossils.

If you explore the region in which you live, you will very likely find different kinds of sedimentary rocks, such as limestone, sandstone, shale, or slate. All of these rocks were formed under the surface of some body of water by the particles of sediment which sank to the bottom. This means, of course, that if you find such layers of rock, the region in

which you live must have been covered by water at some period or periods of the earth's history. If you happen to live in a region where there is a quarry or where there are streams with high banks, you will probably observe that there are layers of different kinds of rock. This means that

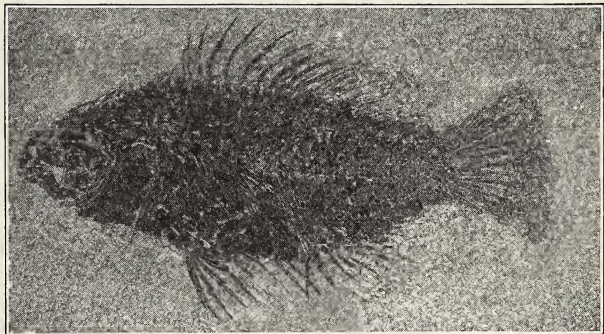


FIG. 206. The fossil of a bony fish, found in Wyoming, which lived many ages ago. Notice how much it resembles our modern perch. (Walker Museum photo.)

conditions changed at different times in that region. Naturally, you would expect the oldest rocks to be at the bottom and the newer rocks on top in the order in which they have been deposited. In general, this is true.

**SUGGESTED ACTIVITY.** Explore the region in which you live. Discover what kinds of rocks there are. Then, by reference to a good book on geology, write a description of the history of your region.

Through long, painstaking labor in all parts of the world, scientists have been able to establish definitely the order in which certain layers of rock have been formed. Furthermore, they have been able from this record of the rocks to get a fairly accurate picture of the kinds of conditions that prevailed at the time the sediment was deposited. These data, together with other types of data, show conclusively

that at certain stages of the earth's history certain areas were tropical seas, and that during other periods they were covered with ice.

For example, remnants of old coral islands can be found in Michigan, which is now the center of our continent. Corals do not exist except where the temperature is at least 68° F.; so at one time Michigan must have been a tropical sea. Deep scratches left on rocks and other evidence indicate that at a later time Michigan was covered by huge glaciers. The geological records of most areas show that they have been repeatedly dry land and shallow or deep seas. Along with these changes in the elevation of the land there have been marked changes in climate.

Since it has been possible to identify the layers of rock in the order of their formation, and since many of these layers contain fossils, it has been possible to obtain records which enable the scientist to determine in general the kinds of living things which existed during different periods of the earth's history and to discover much about the development of living things.

One of the most interesting facts discovered was that none of the fossils is exactly like the living things of today, and that the older the fossil, the greater this difference is.



FIG. 207. This drawing of the *Archaeopteryx*, one of the earliest birds known, has been reconstructed from the fossil remains. It is important because it marks the transition stage in the development of birds from reptiles. It has several distinct reptilian features: jaws with teeth, claws on the upper digits of the wings, and a long, tapering tail of the kind you see on lizards.

It is possible to find in the different rock layers or *strata* fossils of living things which belong to the same family as many of our present organisms. This has been determined by a comparison of the structure of these ancient living things and of living things today. This fact would seem to argue that these forms were the ancestors of our present liv-



FIG. 208. This painting shows animal life in North America fifty-five millions of years ago. The Uintatherium, with three pairs of horns on its head, is supposed to have been the largest animal at that time. The small animals, which are about the size of a collie dog, are four-toed primitive horses. (Herbert photo, from Field Museum.)

ing things. In general, however, the living things of today are more complex in structure than their fossil ancestors.

If we go far enough back into the history of the earth, a period can be found where no fossils of back-boned animals (vertebrates) can be found. Since the fossils of vertebrates are more likely to be preserved than those of the soft-bodied animals, the absence of vertebrate fossils indicates that animals of this type had not yet developed. Furthermore, the rocks show that the first vertebrates were the fishes. These were followed by the *amphibians* (frogs, toads, and salamanders); then came the reptiles, then the birds, and

finally, the mammals appeared. Representatives of these great groups of animals are present on earth today, but a comparison of the primitive fossil forms with the living descendants shows that great changes have taken place in their structure, usually in the direction of more complexity.

Not only does the examination of fossil remains show increasing complexity of some forms of life; it also shows that certain groups which were abundant during one period are not found at all in the next period. In other words, between the time of the formation of one series of rocks and



FIG. 209. This painting shows life on the eastern slope of the Rocky Mountains during the Age of Reptiles, about sixty million years ago. The animals are dinosaurs of various kinds: duck-billed, armored, and bird-like. (Herbert photo, from Field Museum.)

the formation of the next series, the species became extinct. For some reason or other it passed out of existence.

Possibly the most striking example of the disappearance of a species is shown by the *dinosaurs*. These animals were reptiles, and at one period of the earth's history they were the ruling animals. They were of all sizes, ranging from those about the size of our lizards to those which were sixty to eighty feet in length and whose weight was from thirty to forty tons. Their fossils show that they became highly specialized; that is, that they developed to a point where little more change in their structure was possible. Then they perished, and today we have but a few forms of their descendants left, the crocodile being the nearest relative known. Why

they perished is not known for certain. The most commonly accepted explanation is that changes in the environment took place, and that these animals were unable to adapt themselves to these changes. And this brings us to the solution to the question raised in the problem, "What living things survive the struggle for existence?"

**What living things survive the struggle for existence?** Our study has shown us that environmental conditions have changed markedly in the past. These changes in environment brought about different physical conditions: changes in elevation, in temperature, and in quantity of water. When these changes occurred, only three things could happen: The species had to adapt itself through changes in structure and mode of living; or it had to migrate to new regions which were favorable for its development; or it had to perish. If a species had already become too specialized, so that little change could take place, it usually perished. In other forms of life which had not become so specialized, change was possible, and the species survived. Those living things which survived were thus those which were already adapted to a change in conditions or which were able to adapt themselves to the new conditions.

We must not forget that changes in environment and changes in the structure and modes of living of organisms were extremely gradual. It took millions of years for very small changes to take place. Just how these changes in animals can take place is still the subject of scientific investigation. Not enough facts are known to give a definite explanation. Apparently, an individual animal is produced which may differ from its parents in some respect. If this difference in structure is helpful to the individual, that is, if it fits the individual better to its environment, it is more likely that this animal will survive the struggle for existence and produce young. This new characteristic may be passed along to its young. Finally, perhaps only through thousands or millions of years, the descendants possessing this new

characteristic may entirely displace the original form. And this process keeps going on and on. From time to time new characteristics appear in the creature; many of these are disadvantageous, and their possessors die. A few are advantageous and may in many years become established characteristics of the group. A more thorough discussion of the problem of inheritance and the production of new forms of life will be presented in Unit VIII.

**Self-testing exercise 4.** 1. What types of evidence does the paleontologist have upon which to base his opinion of (a) the changes which have taken place in the surface of the earth, and (b) the development of living things?

2. What does the evidence indicate in regard to (a) the changes which have taken place in the surface of the earth, and (b) the development of living things?

#### PROBLEM 5: HOW IS THE BALANCE OF LIFE MAINTAINED?

**STUDY SUGGESTION.** The term "balance of life" refers to the relationship existing between living things which determines the kind and number of plants and animals which can exist in a given region. In the study of this problem three questions should be kept in mind: (1) What is the nature of this relationship? (2) How is this relationship brought about? and (3) What is the result of this relationship?

Studies of the relationship among living things show that they may assist each other by mutual partnership, they may help each other without securing any benefit from the relationship, and they may hinder others in their struggle for the necessities of life. Except in unusual cases, such as occur when grasshoppers or other insects migrate in untold millions into a region, the number of different kinds of animals or plants in a given region remains practically the same. That is, a state of *balance* in nature exists. In this problem we shall learn how the struggle for the necessities of life results in maintaining the *balance of life*.

Why must living things struggle for their existence? As you learned in Unit IV, one of the characteristics of living things is their ability to have young. By means of this ability animals and plants continue to exist. The elephant, which is perhaps the slowest breeder in the animal kingdom, begins to produce young when it is thirty years old. During its lifetime, which is about one hundred years, it produces an average of six young. Let us suppose that the young of the original pair of elephants all lived and that

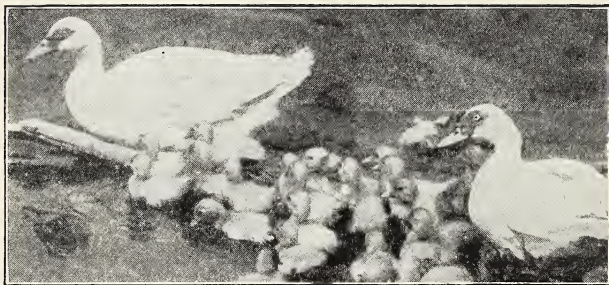


FIG. 210. Although a pair of ducks may produce all these young in one season, yet the number of adult ducks does not at all increase in proportion to the number of young. (Lynwood M. Chace photo.)

each pair produced six elephants in their lifetime. At the end of 750 years there would be produced 19,000,000 elephants, all descendants of the original pair.

In contrast to the elephant, let us examine a few animals which reproduce many young. The codfish lays as many as 9,000,000 eggs a year. Half of these hatch into males, and half into females. If all of them lived and reproduced, at the end of the second year there would be 40,500,000,000,000 fish descendant from a single pair. At the end of the third year there would be 4,500,000 times as many fish as in the second year. Another rapid breeder is the mosquito. A single female lays 400 eggs, half of which are females. Each of these females becomes mature in ten days and lays eggs.

If the eggs laid by one female developed to maturity and reproduced, in three months the number of mosquitoes from this female would be 102,914,592,864,480,008,004,001.

Our common plants, as you know, reproduce by means of seeds. When winter comes, these plants die, but their continuation for succeeding years is secured through their seeds which have been scattered and buried in the soil.

**Experiment 40. How many seeds are buried in the soil over an area of one square foot?** (a) Select a vacant lot which is covered with weeds in the summer. Measure off a square foot, and remove the soil to a depth of three inches. Place the soil in a box about a foot square, and provide the proper growing conditions. Keep count of the number of plants that take root and grow.

(b) It is an interesting experiment to obtain soil from different localities and compare the number of seeds found.

Darwin made an experiment somewhat similar to the one outlined above. He measured off a plot of ground two by three feet and counted the number of plants which started growth. He found that 357 seeds developed into plants in this area, making an average of about fifty-nine plants per square foot. Suppose that each of these 357 seeds grew into a new plant which produced ten seeds each. (Ten seeds is a very small average.) The following year there would be 3750 plants produced. If this continued for a period of ten years, there would be over 3,500,000,000 plants produced in the tenth year. If each of these plants required an area of four square inches for growth, 35,571 square miles would be required. If this number of square miles would be required for the offspring of the plants grown originally on an area of six square feet, imagine, if you can, how many million square miles would be required for the growth of all of the seeds produced each year.

The figures given in the last two paragraphs concerning the possible rate of reproduction are correct, but it is evident that if this rapid increase actually took place, in a very

short time the descendants of a single pair of animals or of a single plant would cover the entire surface of the earth. Observation of the living things about us shows that this increase does not take place. Year after year in the same locality the number and kinds of plants remain about the same. How is this brought about?

All living things require certain conditions and materials in order to live. The energy of most living things is directed toward securing these conditions and materials. As a result of the tremendous over-production of living things, there is a scarcity of food and of room to grow. This of course brings about a competition among living things for the necessities of life. In one sense every plant is an enemy of every other plant. This is particularly true where several plants are trying to obtain a foothold in the same space. From the moment the seeds start to grow, competition begins. Beneath the soil the struggle is for water and minerals, while above the soil it is for light and air.

Some plants develop root systems rapidly, others slowly. In general, the plant with a rapid-growing root system has a great advantage because it gets the first chance at materials from the soil to aid its growth. If it can push its way upward through the soil and develop its leaves ahead of another plant, its chances of success are greatly increased. The stronger plant ultimately wins, and its competitors are either destroyed or weakened to such an extent that their production of seed is lessened. The earth cannot provide space, food, and light for the growth of all of the seeds produced by plants. The result of the competition for these materials and conditions is the survival of the strongest or best adapted plants, and the death of the weaker or poorly adapted plants.

The frog lays many thousand eggs in a season. If you have ever been frog-hunting, you know that in any given stream or pond the number of frogs remains about the same from year to year. What becomes of the eggs? Many of them are used by other animals for food. Some of them never

start growth. Those that develop remain for some time in the tadpole stage. In this stage they are attacked by leeches and water bugs which suck the blood from their bodies. Of the frogs that mature, many are eaten by man, water birds, crows, snakes, and water rats. The result is that, in spite of the number of eggs produced each year, the number of frogs in a pond remains about the same from year to year. (See Figure 156, page 179, and Figure 159, page 182).

**How is a state of balance**

**secured?** Living things

must not only compete

with other living things in

order to live, but they must

also struggle with the cli-

mate. An extremely cold

winter may destroy the en-

tire crop of winter wheat

and clover. A late fall may stimulate the growth in young

fruit trees so that they are unprepared for the intense cold of

winter. A period of warm weather early in the spring may

cause the fruit buds to start growth, only to be killed by a

heavy frost. Heavy rains and floods in the spring wash away

the seeds of many plants. Millions of living things are killed

every year by unfavorable climatic conditions.

The competition between living things of the same kind

and between living things and their enemies has brought

about a state of balance in nature. There is only a certain

amount of space and food. Nature cannot supply the condi-

tions and materials necessary for the growth of all of the

living things that commence life. Hence, many of them must

die. If conditions happen to be such that a large number



FIG. 211. A relentless struggle for existence is ever going on around us; and although many of these struggles seem tragic to us, they are part of Nature's scheme for maintaining a balance of life.

of a certain kind of animal succeeds in getting started, the result is always an increase in the production of the enemies which feed upon that animal. For example, if a certain kind of insect succeeds in producing a large number of young, the birds which feed upon this insect are able to increase because of the increase in the quantity of available food. This increase in the number of birds increases the number of enemies of the insects, and results in their wholesale destruction. When the number of insects gets back to normal, there is not enough food for the over-supply of birds; so they die because of lack of food. The result is that conditions finally are balanced, and the supply of birds and insects falls to normal; that is, the balance of life is restored.

The close inter-relationship which exists among living things is shown by the balanced aquarium.

***Experiment 41. How is a balanced aquarium constructed? (a)***

A balanced aquarium can best be constructed with a rectangular glass aquarium with a capacity of six or more gallons. Obtain some sand and thoroughly clean it in running water. Cover the bottom of the aquarium to a depth of about two inches. Obtain a supply of tap-water which has stood in open containers for about a week, or clear pond water. Pour the water against the side of the aquarium so that it will not strike the sand. A few plants such as *Vallisneria* (tape grass), *Sagittaria* (arrowhead), *Elodea*, and *Myriophyllum* should then be planted.

Set the aquarium in a place where it can obtain direct sunlight for two or three hours a day. If the water becomes cloudy and the plants do not grow, reduce the number of plants. Allow the aquarium to stand for several days, and then add three or four snails, two or three tadpoles, four or five small goldfish, mud minnows, catfish or sticklebacks, a small clam, and one baby turtle. The water should remain clear. If it becomes cloudy, the water should be changed, or the number of plants or animals, or both, should be decreased. The correct number of plants and animals must be determined by experience.

(b) The animals should be fed sparingly. A few animals, such as cyclops, daphnia, and cypris, should be kept in the aquarium

to serve as food. These can usually be obtained from pools by means of a fine-meshed net. In addition to this, a small quantity of fish food and a live fly or two for the turtle should be added each day.

It is possible to make an aquarium so that there is a perfect balance, that is, so that no food or other materials need be supplied. Under such conditions the aquarium may be covered and sealed air-tight, and the plants and animals will continue to live. The relationship which exists between plants and animals is as follows: The plants, using water, carbon dioxide, and minerals, manufacture foods. During this process they give off oxygen. The animals eat the food manufactured by the plants, breathe in the oxygen, and give off carbon dioxide into the air and certain solid waste products which contain minerals into the soil. These materials are again used by plants in the manufacture of foods. This completes the food cycle (Figure 212).

**Self-testing exercise 5.** Study Figure 212 and make a list of all the facts which it shows. Explain what the figure shows.

The balance of life is in an extremely delicate state of adjustment. A change in weather conditions, an increase or decrease in the production of a certain plant or animal, may throw the balance one way or another and have far-reaching effects. For example, let us see the consequences of an automobile accident on a busy street, when traffic is held up for a time until the wreck is cleared away.

A business man is going to a distant city where he has a conference shortly after his train arrives. Because of the accident he misses his train, and the conference must be postponed. He must telegraph this information to some member of his conference group, who in turn must notify the other members. Each of these members must in turn rearrange his plans. The failure to hold the conference may result in some rival organization obtaining a contract for certain supplies. This may result in closing down a certain

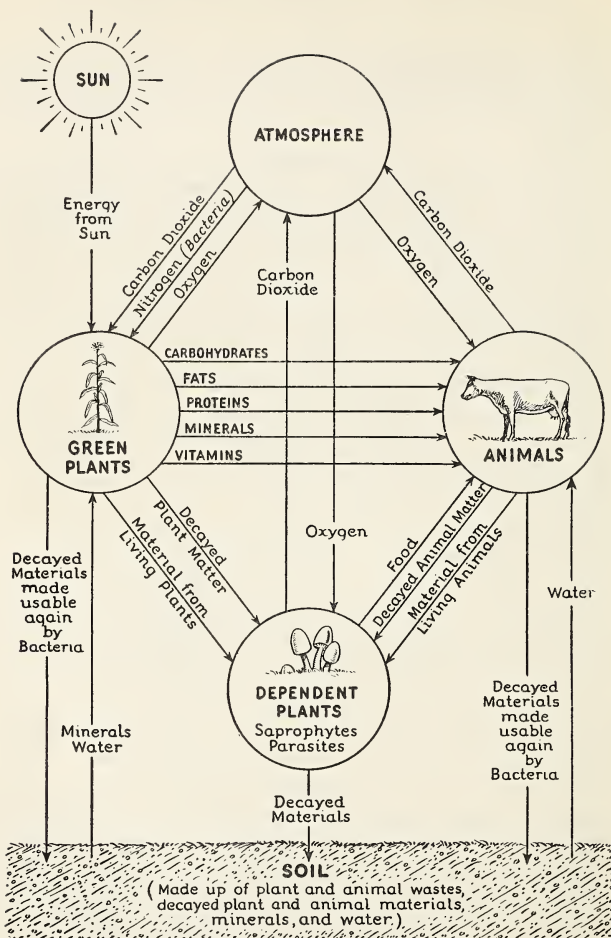


FIG. 212. Chart of the food cycle in Nature.

factory. The workers in this factory may be forced to move to another city or engage in some other line of work. Thus an automobile accident in Chicago may change the lives of hundreds of people in a town a thousand miles away. You can probably think of many examples in which some unusual event has had far-reaching effects upon your life and the lives of others.

Charles Darwin was the first to show clearly the inter-relationship and interdependence of living things. In one of his investigations he showed that the supply of clover was dependent upon the number of cats. Darwin observed that bumblebees visited clover for nectar, and in passing from flower to flower, distributed pollen. In order to determine the value of this distribution of pollen from flower to flower, he covered 100 heads of clover so that the bumblebees

could not get to them. None of these heads produced seeds, while one hundred heads which were not covered produced 2700 seeds. The production of clover seed is thus entirely dependent upon the number of bumblebees. If all of the bumblebees were killed, the clover plant would probably disappear. Field mice destroy the nests and young of the bumblebees. An increase in the number of field mice therefore results in a decrease in the number of bumblebees and a decrease in the number of seeds produced by clover. Field mice, in turn, are the prey of cats. If the number of cats is increased, the number of field mice is decreased, and as a consequence there are a greater number of bumblebees. Thus the crop of clover seed is dependent to some extent upon the number of cats.

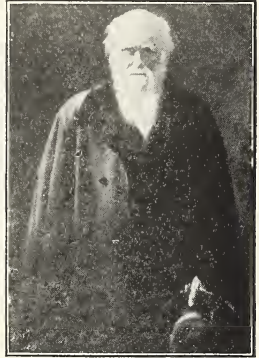


FIG. 213. Charles Darwin (1809-1882), the greatest English naturalist of the nineteenth century.

This interdependency of living things is so complex that any change in the number of a given kind of living thing brings about a change throughout the whole living world until a new balance is obtained. An interesting example of



FIG. 214. Cottony cushion scale. (U. S. Department of Agriculture photo.)

the results produced by the introduction of a new animal in a region happened in California. Some young trees which were imported from Australia in about 1868 brought with them a large scale insect, the cottony cushion scale. This insect attacked the orange and lemon

trees and threatened the ruin of the entire industry. A scientist was sent to Australia to discover how the number of the insects was kept down. He soon discovered that the cottony cushion scale was kept in check by a small beetle (*Novius cardenalis*) which devoured it. He brought some of these beetles to the United States and released them in the orange groves, with the result that the number of cottony cushion scale was reduced to such an extent that it no longer does much damage. In order, however, to prevent any more outbreaks, these beetles are today raised in large numbers in Sacramento and are sent to any groves where the cottony cushion scale appears in large numbers.

Impressed by the success of California, Florida fruit growers decided to import the beetle to destroy some other kinds of scale insects which were ruining their trees. A few of the beetles, together with some cottony cushion scale to serve as food during the journey, were accordingly secured and released in the orange groves. Unfortunately, however, the beetles would not eat the other type of scale insects.

The result was that the beetles died, and the cottony cushion scale flourished. This example shows that the balance in nature is extremely delicate and that even man must be careful in disturbing it.

The useless slaughtering of any kind of animal may result in an entire change in the balance of life. For example, what effect would the destruction of birds have? It is estimated that the birds in the state of Massachusetts destroy 21,000 bushels of insects a day (each bushel containing 120,000 insects) for a period of five months in the year. The wholesale destruction of birds would result in an increase in insects which would destroy in a short time every green plant in the United States. This would also result in the destruction of all animal life, including man.

Throughout the millions of years during which life has existed upon the earth, the struggle for existence has been going on. The result has been the production of a balance between living things. Nature, if left alone, sees to it that there is no permanent, great increase in the number of a certain kind of living thing. Man is the only disturber of this natural balance, but even he must carefully determine what living things to preserve and what living things to destroy lest he disturb the balance too greatly and bring about the wholesale production of living things which might result in his own extinction.

**SUGGESTED ACTIVITY.** Make a list of the activities of man which are directly related to self-preservation.



FIG. 215. A monument in Salt Lake City, erected to the sea gulls that saved the early settlers from a grasshopper invasion. (Courtesy of the Salt Lake City Chamber of Commerce.)

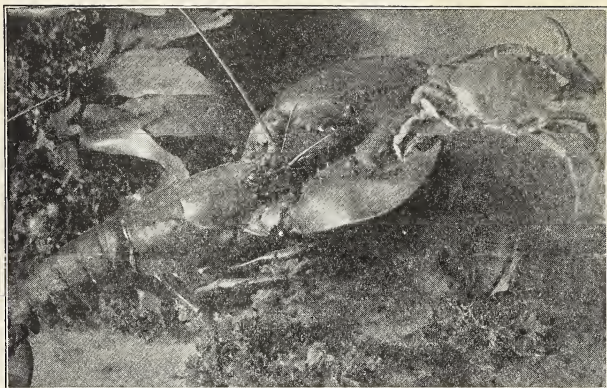


FIG. 216. Here a lobster has captured a soft-shelled crab with its large pincers and is about to dismember its victim for eating with its smaller pincers. This little drama illustrates one of Nature's ways of preventing over-production, in this case of crabs, and so maintaining the balance of life.

#### PROBLEM 6: HOW HAS THE PRESENT GEOGRAPHIC DISTRIBUTION OF ORGANISMS COME ABOUT?

Everyone knows that not all kinds of plants or animals are found in every region. A big-game hunter does not hunt elephants or tigers in North America, because he knows that neither of these animals is found in this region. Yet at one time in the history of the earth this country abounded in the hairy mammoth, a distant relative of the elephant, and also in the saber-tooth tiger (Figures 217 and 218). In North America today we have deer, beavers, field mice, bears, and other animals.

Strangely enough, not one of these animals is found in Africa. There are two branches of the camel family: the animal which we know as the camel, and the llama. The camel is now found only in Asia and North Africa, while its

distant cousin, the llama, is found only in South America. Alligators are present in but two regions—southeastern United States and central China. Many examples can be given which show that certain animals exist only in one region; that certain other animals are widely distributed; and that other animals of the same family exist in widely separated regions, but not in the regions between them. How can these facts be explained?

Of one thing we are certain: No species of animal or plant can continue to exist in a region to which it is not adapted. It might be possible to explain the geographic distribution on the basis that organisms are found in regions to which they are adapted. Of course, this statement is true, but it is only a half truth. There are many regions nearly alike in physical conditions which have different kinds of animals. Furthermore, if certain species are introduced into a region, sometimes they are able to compete so successfully with the native organisms that they almost drive them out. For



FIG. 217. A hairy mammoth.

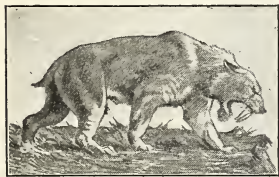


FIG. 218. A saber-tooth tiger.

example, at one time there were no English sparrows in this country. They were brought from Europe by man and were so well fitted to this environment that in many places they are the most abundant species of birds. A similar event took place in Australia. Before man took rabbits to Australia, none were there. Now they have multiplied to such an extent that they are a serious menace to the crops. The examples that have just been given show that we must seek further than "fitness to the environment"

if we are to find an explanation of the geographical distribution of plants and animals.

In the preceding problem we cited evidence to show that the land and water surface of the earth has changed in its proportions at various times in the history of the earth. We found, furthermore, that the living things of the past were unlike those of the present; that great changes have taken place in life at different periods. It is in these two facts that we find an answer to the riddle of geographical distribution.



FIG. 219. A mother kangaroo with her young in her pouch. (Herbert photo.)

While it will not be possible to present all of the facts upon which scientists base their theories as to the present distribution of living things, an example or two will make clear their method of interpretation. Let us turn

first to the *fauna*, that is, the animals, of Australia.

Australia is the home of the *marsupials*. The marsupials include the kangaroo, the wallaby (similar to the kangaroo, but smaller), the rat kangaroo, the koala or tree bear, the wombat, and the tasmanian devil. None of these animals is found anywhere except in Australia and its near-by islands. Another member of this group, the opossum, is found only in the United States. These animals are grouped together because of their method of reproduction and care of the young. The eggs are retained in the body of the mother until they hatch. The young are very small (in the opossum they are less than one inch in length), and they usually remain in a pouch on the belly of the mother during the nursing period.

In this way they are taken care of until they are ready to care for themselves.

At one time in the history of the earth, marsupials were found in America and Western Europe. Now, with the exception of the opossum, they are found only in Australia. Our problem is, therefore, to explain their disappearance from certain regions and their marked development in Australia.

The fossils indicate that the marsupials probably first originated in North America and that they migrated from there to Europe and Australia. This, of course, would be possible only if these continents were connected by land; and this is believed to have been the case. Some time after the marsupials entered Australia, the land connection was broken, so that Australia was separated from the other continents by many miles of water. This, of course, would be a barrier which no land mammals could cross. The marsupials in Australia were thus cut off from the rest of the world and were able to develop without competition from other mammals. After the break between Australia and the other continents a new type of mammal, the *placental* mammals, originated—probably in some northern continent. Since the land connection was broken, these animals could not enter Australia.

Now before we continue our story, let us summarize the series of events which have been described: (1) Marsupials appeared in North America and spread to the present continent of Australia; (2) Australia was cut off from the northern continents by the ocean; (3) placental mammals appeared in the northern continents; (4) placental mammals came into competition with the marsupials in the northern continents; and (5) marsupials continued to develop in Australia without competition from placental mammals.

The marsupials as a group are not as well fitted to survive the struggle for existence as the placental mammals. In placental mammals (which include all of the common mammals we know) the blood vessels in the mother's body are

brought in close contact with the young embryo by a *placenta*, so that nourishment may pass from the mother to the embryo. This makes it possible for a greater amount of development in the young animal before birth, which, of course, gives it a better start in life, so that it is more likely to survive. In addition to a more efficient method of reproduction, the placental mammals are also equipped with better brains than the marsupials. Because of their better adaptation to the environment, they won out in their struggle with the marsupials, which became extinct (with the exception of the opossum) in the northern continents.

Why the opossum has survived is difficult to say. It produces ten or twelve young at a time, while most of the other marsupials produce but one or two. It lives in trees, feeding at night and remaining in its hole during the day. It also has the peculiar habit of pretending death when in peril, but when necessary, it can be a dangerous fighter. Perhaps these characteristics have helped it to hold its own among the other animals.

The riddle of the geographic distribution of plants and animals can thus be partially interpreted by reconstructing the story of the past. At the present time a complete picture of the history of the earth is not possible, because the various strata of rocks have not been sufficiently explored; hence our knowledge of geographic distribution is not complete. The facts which have been presented were selected to show how it is possible for scientists to interpret life in both past and present through a study of the various strata of rocks and their fossils. The facts and their interpretation explain some of the features of geographical distribution which until recent times were puzzles to man, and furnish further evidence that living things are found in the environments to which they are fitted by structure and by modes of living.

In Problems 1 and 2 we found that there are certain general kinds of habitats, such as those presented by the frigid,

temperate, and tropical zones. Within these regions are hydrophytic, mesophytic, and xerophytic habitats. Each of these can be further divided. For example, a hydrophytic environment can be divided into salt and fresh water habitats, or into surface zones and deep-sea zones. Different forms of life are found in each of these surroundings because of the different conditions which are present. Because of the great variety of conditions and the different ways in which these conditions are combined, the distribution of living things is an extremely complex problem to solve. In order to see how complex are the inter-relations of the different conditions, let us now consider some of the factors which account for the distribution of plants.

In general, the factors which influenced the distribution of plants may be divided into two groups: (1) those which are geographic in character, and (2) those which are

topographic in character. The geographic factors are those which are determined by the seasons, latitude, light, temperature, movements of the air, and amount of moisture. The topographical factors are those which are concerned with the composition and nature of the soil. We shall now consider briefly the effect of these factors upon plant distribution.

As you have probably observed in the forest, the light requirements of plants differ. Some plants need a great deal of light for growth, others can grow in shaded positions, and still others grow better in the absence of direct sunlight.



FIG. 220. A roadway cut through the heart of an aspen poplar forest shows that the lower limbs of the trees have been killed by the shade, leaving clean trunks as the trees grew tall to reach the available light. (W. C. McCalla photo.)

This difference in light requirement is one of the important factors which determine which species will survive in the struggle for existence. Some trees, for example, can grow in the dense shade of the forest, while others cannot grow so well. More young trees start growth than can survive, and in the resulting competition for food, the tree which is best adapted to the conditions present will emerge the victor.

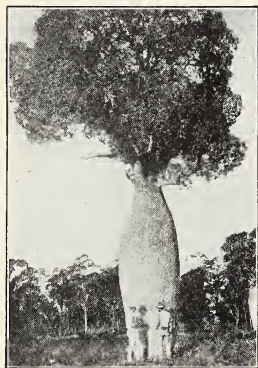


FIG. 221. The trunk of the Australian bottle tree is adapted for storage of water.

The maximum and minimum temperatures of regions are partly dependent on the latitude. The limits of high temperatures and low temperatures which living things can withstand vary greatly in different species. Some trees, for example, can stand a temperature of  $-70^{\circ}\text{C}.$ ; others are killed when the temperature falls below zero. We have already studied the effects of the difference in the amount of moisture available and have found that only certain types of plants can grow under different moisture conditions. Plants are affected not only by the quantity of water which falls during a given year, but also by the time of falling. For example, if all of the rain falls within a few months of the year, while it is dry for the rest of the year, the vegetation will be different from those regions in which the same amount of rain is distributed throughout the year.

The direction and the force of wind are important to plant distribution in that air movement assists in the distribution of the pollen and the seeds of plants. The force of the wind is also important in determining the kind of plant which can grow. In exposed regions where the force of the wind is very great, short plants are much better protected from the

wind than tall plants. A rapid air movement also dries the plants; plants which are provided with xerophytic adaptations are thus best fitted to this environment.

And now let us turn to the topographic factors which affect plant distribution. There are, of course, many different kinds of soil; sandy, lime, clay, loam, and saline are some of them. Each of these kinds of soil varies in composition and in structure. That is, some contain certain kinds of minerals and organic materials, while others contain other minerals and different proportions of organic materials. Some soils are porous and admit the free circulation of air; others are non-porous and exclude air. Some soils are warm, and others are cold. Different types of soil thus provide different types of growing conditions. It is, therefore, to be expected that one would find different kinds of plants growing in different kinds of soil. And, of course, this is what actually happens.

The facts presented in this problem show clearly the relation between fitness to the environment and geographic distribution. In general, it is safe to conclude that living things are found only in those habitats to which they are adapted by structure and habits. On the other hand, living things are not necessarily found in all of the regions to which they are adapted. Barriers such as mountains, deserts, and oceans may have prevented their migration from the regions in which they developed to other regions which are favorable to their growth. Where these barriers did not exist, species developing in one region gradually spread to other regions where they came into competition with other species. If they were better fitted than the original inhabitants, they triumphed in the struggle for existence and forced the other species to migrate or die. If they were not better fitted, they were the losers in the struggle and survived only in the region where they developed.

The fossil records show a continued development of living things in terms of complexity. New structures developed,

and new forms of living things came into existence. These new forms, few in number at first, came into competition with the existing species. If they were better adapted, they replaced the old species, only in turn to be replaced by new living things which were still better fitted for life than they. Even today this struggle is still going on; the inefficient are destroyed, and the efficient thrive and multiply.

**Self-testing exercise 6.** Write a paragraph in which you show how the geographical distribution of organisms is related to the changes which have taken place in the earth's surface, the structure of organisms, and the struggle for existence.

#### ADDITIONAL EXERCISES

1. Scientists have traced rather completely the development of the horse and the camel. Consult an encyclopaedia or some other reference book and prepare a story about either of these animals.

2. Birds, flying foxes, and flying fishes are fitted to movement through the air. Discover how the structures of these kinds of animals differ.

3. Choose any wild animal that you wish. Make a careful study of this animal and determine, as nearly as possible, all of the types of structure which fit the animal to its environment.

4. If an organism becomes very highly adapted to its particular environment, in the end this may prove to be a disadvantage. Explain how this might happen.

5. Prepare a report upon prehistoric animals.

6. Prepare a report upon prehistoric man.

7. Many tropical plants have thick-walled leaves and tips in the form of gutters. What advantage is this to the plant?

8. Most of our broad-leaved trees lose their leaves in the autumn. Explain why this is an adaptation to environment.

9. The upper epidermis of leaves is usually thicker than the lower epidermis. Explain.

10. Why do the stomata of plants living near an abundant water supply rarely close?

11. Why are black people better adapted to hot, sunny climates than white people?

## UNIT VI

### HOW ARE LIVING THINGS CLASSIFIED?

#### PRELIMINARY EXERCISES

1. All living things are alike in the following ways: ....(a)...., ....(b)...., ....(c)...., and ....(d)....
2. All animals resemble each other in these four ways: ....(a)...., ....(b)...., ....(c)...., and ....(d)....
3. Some of the ways in which animals differ are as follows: ....(a)...., ....(b)...., and ....(c)....
4. The following are some groups of animals I have seen: ....(a)...., ....(b)...., ....(c)...., ....(d)...., ....(e)...., and ....(f)....
5. All plants are alike in the following ways: ....(a)...., ....(b)...., ....(c)...., and ....(d)....
6. Some ways in which plants differ from each other are as follows: ....(a)...., ....(b)...., and ....(c)....
7. The following are some groups of plants I have observed: ....(a)...., ....(b)...., ....(c)...., ....(d)...., ....(e)...., and ....(f)....
8. (a) What are the common methods employed to classify plants into groups? (b) To classify animals?
9. How do scientists classify living things?
10. Why is it necessary to classify living things?

#### THE STORY OF UNIT VI

If a new or strange plant or animal is brought to the biology class, some one is sure to ask at once, "What is it?" Sometimes this is rather a difficult question to answer, because there are thousands of different kinds of living things. An expert in botany or zoology, however, can identify the specimen and tell its name. When we stop to think, we realize that every known thing in the world has a name. You may wonder who named things, and why each was given the particular name it bears. For example, do you know who named you and why you had to have a name? Have you ever named anything?

It would be rather difficult to talk about the places we have visited, persons we have met, things we have seen, tasted, smelled, touched, or heard if they did not have names. Man, no doubt, began naming things as soon as he learned to talk. In fact, he may have learned to talk through his desire to indicate certain objects. Perhaps, in those early days when he had no fixed home, but wandered about from place to place seeking food and shelter, man devised words



FIG. 222. It is easy to see that there is a close relationship between the bullfrog and the leopard frog. There are, however, certain very important differences between them. A large dictionary will tell you that the bullfrog is known as *Rana catesbeiana*; the leopard frog bears the name *Rana pipiens*. There are about seventeen kinds of frogs in North America. (Lynwood Chace photo.)

or sounds to designate plants and animals that were good to eat and those that were poisonous or otherwise harmful. Usually these names indicated the appearance of a plant or animal or something peculiar about its habits.

The mere naming of things, however, ceased to satisfy man when he began to think about the world in which he lived. As he studied his environment, he discovered so many things about it that he found it necessary to devise some sort of system of grouping together objects, and forces, and

phenomena which possessed certain common characteristics. In his effort to systematize Nature, that is, to find methods of classifying or arranging various things into groups, man found it necessary to make a more and more detailed study of the characteristics of things. He thus learned more and more about the objects of his environment.

Efforts to group organisms having similar characteristics, that is, to classify living things, began a long time ago. At first, the scientist was interested primarily in grouping living things so that they could be conveniently arranged, described, and catalogued. One of the earliest attempts to classify living things was made by the great Greek thinker, Aristotle. He divided animals into two groups, those with red blood and those without. Each of these groups was further divided. The red-blooded group was divided into (1) mammals—beasts which bring forth their young alive; (2) birds; (3) four-footed, or creeping, things which lay eggs; and (4) fishes. The group without red blood was divided into (1) animals with soft bodies, such as the octopus; (2) animals with soft shells and jointed bodies and limbs, such as lobsters and crabs; (3) insects; (4) animals with hard, outer shells, such as the oyster; and (5) animals resembling plants, such as sponges and sea-anemones.

Since these early attempts to classify living things, many different systems have been proposed. All of them but one, the *Linnaean System*, have been discarded. The Linnaean System, as you will see when you study this unit, has all of the advantages of the other systems; that is, it is convenient and eliminates all confusion. At the same time, it takes into account the relationship, or *kinship*, of the various animals. Since it is based on kinship, the classification is natural rather than artificial. For example, foxes, wolves, and jackals are grouped into the same family because they have a blood relationship with each other. It is believed that sometime in the past a species of animal existed from which the fox, wolf, and jackal descended. In other words, these

animals have a common ancestor. How this relationship has been traced and why man believes that our present forms of life are the result of changes which have taken place from generation to generation you will learn in this unit.

Through the study of living things and their classification into groups man has learned many things which have helped him to understand the world in which we live. He has also learned much about how the different forms of life have developed. In a practical way this knowledge has been



FIG. 223. Here are some members of the gourd family. Probably you would not have thought that the muskmelon and the cucumber are related, but botanists know that they belong to the same family.

extremely valuable. How do you suppose that a knowledge of the kinship of living things has helped man?

In the problems of this unit the common everyday ways of classifying living things will be compared with the methods employed by biologists—the trained students of plant and animal life. A few specific plants and animals selected from the higher and lower groups will be studied in detail. This will give you a basis for comparing and classifying living things in accordance with their structures and functions. You will have opportunities of discovering for yourself why it is possible to group living things, and the benefits that are gained through these scientific groupings.

### PROBLEM 1: WHY DOES MAN CLASSIFY LIVING THINGS INTO GROUPS?

How have plants and animals received their common names? Man has always depended upon plants and animals for food, clothing, and shelter, and it is likely that even in primitive times he found ways of naming and sorting living things. He learned by experience that some plants and animals were good for food, while others were unfit to eat. He also found that some animals were harmless, while others were savage and should be avoided.

As man became more highly civilized, he found more and more uses for the plants and animals that surrounded him. Through using living things he learned to know them and name them. Long before he could read or write, man probably had devised names for many things. The methods employed by the American Indians in naming persons, places, rivers, lakes, mountains, trees, birds, animals, and other things well illustrate the desire of primitive man to name things. With the Indians, as you know, the name given to a person, thing, or place was generally a descriptive one. For example, the great river that flowed through his country was called the Mississippi—Father of Waters. Although many of the names were long, awkward, and haphazard, they served the purpose of the red man well.

Long before scientific names were thought of, thousands



FIG. 224. It is easy to understand how the jack-in-the-pulpit got its name. (W. C. McCalla photo.)

of plants and animals had been given common names. How these common names originated would be a fascinating study. For your interest and to illustrate the common or popular way of naming plants the following list is included.

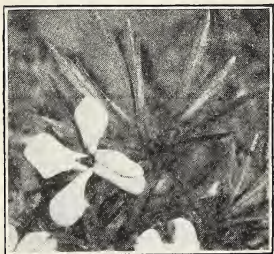


FIG. 225. From its claw-shaped leaf the bird's-foot violet gets its common name. (L. W. Brownell photo.)

As you read this list, note that some characteristic of the plant, such as its shape, size, color, or use, is singled out and used as part of its common name.

*Size.* Giant redwood, great Indian plantain, dwarf cornel

*Shape of Fruit.* Kidney bean, sheep-nose apple, ox-heart cherry, crook-neck squash

*Color.* Redroot, snowberry, blueberry, blackberry

*Odor.* Skunk cabbage, sweet pea, stinkhorn, sweetbrier

*Taste.* Sugar plum, sour gum, bittersweet, honey dew

*Touch.* Velvet leaf, prickly ash, touch-me-not, rosinweed

*Part of an Animal's Body.* Lion's foot, squirrel tail, ox-eye daisy, crane's bill

*Texture of Wood.* Hard maple, soft maple, ironwood

*Medicinal Use.* Self-heal, boneset, heart's-ease, balm-of-Gilead

*Length of Life.* Dayflower, century plant, everlasting

*Habitat.* Sand cherry, river maple, mountain ash, pond lily

*Habit.* Spreading dogbane, trailing arbutus, climbing rose

*Time of Blossoming.* May apple, morning-glory, spring beauty

*Time of Fruiting.* June berry, summer haw, fall pippin

*Indian Name.* Squash, hickory, kinnikinnick

*Heavenly Bodies.* Star-grass, sundew, moonflower, Venus's looking-glass

The names of the oak trees in the following list will suggest how they were named: Barren, basket, bear, black, black jack, black scrub, bur, chestnut, cow, fern, gray, iron, Jerusalem, laurel, live, mossy-cup, over-cup, pin, post, red, scarlet, shingle, Spanish, swamp-post, swamp-Spanish,

swamp-white, water, white, willow, yellow, yellow basket. If you examine a list of the common names of insects, fish, reptiles, birds, and mammals, you will probably see that they have received their names in a manner similar to that of the plants.

You are also familiar with the fact that man has grouped together living things which are similar in shape, habitat, use, length of life, habits, and other characteristics. For example, read the following lists and note the ways which man has used to classify living things into groups.



FIG. 226. The tufts, or tussocks, of hair give the tussock caterpillar its name. (G. T. Hillman photo.)

#### PLANT GROUPS

|            |           |          |          |            |
|------------|-----------|----------|----------|------------|
| herbaceous | grain     | thicket  | jungle   | medicinal  |
| woody      | fruit     | field    | desert   | ornamental |
| evergreen  | vegetable | pasture  | alpine   | weed       |
| hardy      | forest    | forage   | aquatic  | flower     |
| annual     | meadow    | orchard  | tropical | tree       |
| biennial   | bog       | vineyard | edible   | shrub      |
| perennial  | swamp     | prairie  | textile  | vine       |

#### ANIMAL GROUPS

|             |              |           |              |           |
|-------------|--------------|-----------|--------------|-----------|
| carnivorous | burrowing    | wild      | shore        | pests     |
| herbivorous | migratory    | swimming  | fowl         | farm      |
| omnivorous  | hibernating  | floating  | game         | livestock |
| land        | nocturnal    | marine    | warm-blooded |           |
| water       | diurnal      | wading    | cold-blooded |           |
| arboreal    | domesticated | shellfish | fur-bearing  |           |

**Why are objects grouped?** Grouping objects which have certain characteristics in common and assigning a name to stand for all the objects of that group are of great advantage to man. For example, if someone tells you that he wants

you to look at the chairs in a room, you can immediately pick out the chairs from the other objects. "Chair" is a name assigned to furniture which possesses certain characteristic features. Beds, tables, davenports, and bookcases

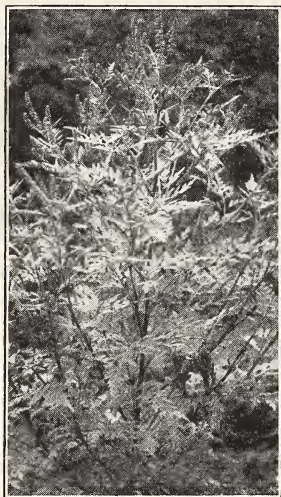


FIG. 227. By what name is the common ragweed known in your locality? (L. W. Brownell photo.)

cannot be classified as chairs because they do not possess the essential features of this class of objects. If there were no name for the objects known as "chairs," a person would have to describe the object minutely before you would have an idea of what it was. Imagine how difficult it would be to think about an object, such as a chair, if you had no name for it. Words which stand for groups of objects resembling each other thus help us in our thinking.

The library is another illustration of the advantage that results from organization and classification. Books that deal with the same subject-matter are placed together. If books were placed on the shelves according to their color, size, or shape, there would be confusion in trying to use them. For the convenience of the librarian and the reader, the books are carefully classified and catalogued according to content. If you wish to consult a certain author or to find material concerning a certain subject, the desired information may be found in the card catalogue. Through classification the books are arranged in an orderly fashion, that is, in accordance with some plan of organization. Knowing this plan of organization enables us to find the book we wish in the shortest possible time.

And now that we understand some of the reasons why classification is necessary, let us turn to the classification of living things. The common method of naming and classifying living things has resulted in great confusion. A given plant or animal may have several common names, or a number of different plants or animals may have the same common name in different parts of the world. For example, the sycamore that we know is an entirely different tree from the sycamore of the Old World. The common ragweed (Figure 348) is known as Roman wormwood, bitterweed, wild tansy, hayweed, hogweed, carrotwood, and stammerwort in as many different parts of the country. The flicker is known by a dozen different names, such as golden-winged woodpecker, yellow hammer, high-holer, and northern flicker. Since common names differ so widely, it is evident that they are useless to the scientist who is attempting to describe exactly all forms of life and to classify them into groups.

A universal and accurate system of naming living things is necessary from another standpoint. Scientists from all over the world, speaking many different languages, are constantly discovering new types of living things. In order that they may know of the discoveries of others and be able to share their discoveries with them, some method of classification must be decided upon. Without some universally recognized system of classification the names and descriptions of all of the hundreds of thousands of kinds of plants and animals would have to be placed in a long list. Imagine how difficult it would be to read through this entire



FIG. 228. What name do you use for the flicker? (L. W. Brownell photo.)

list to find out if someone had already discovered a plant or animal like the one you had just found. Yet this would be necessary without a universal system of classification.

The necessity for some method of classification has been



FIG. 229. Karl von Linné.

apparent to biologists for hundreds, if not thousands, of years. The history of the many schemes which have been tried and discarded when they failed to bring into a single system all of the hundreds of thousands of living things is a fascinating story. The system which finally survived is called the Linnæan System, after its founder, Karl von Linné, a great Swedish naturalist of about two hundred years ago. In a most important work called *Systema Naturæ*, which appeared first in the year 1735, he outlined his system of classifying and nam-

ing living things. His classification was based on kinship and on differences and likenesses in structure rather than on external appearance or habits, such as had been followed in the earlier schemes. How this method of classification is used you will discover in the next problem.

**SUGGESTED ACTIVITY.** Obtain as many kinds of seeds as you can, and work out a scheme for classifying them. For example, one basis of classification is color; another is shape. If you will examine each seed carefully, you will find many different characteristics which may be used to distinguish it from other seeds. Plants are commonly identified by means of a key. If you will consult a plant key, you will see how such keys are made.

It would be interesting to construct a key for the seeds which you have gathered, so that another person would be able to identify each seed. To make a key, first decide on some one characteristic which will divide all seeds into two classes. For example, color

might be used. Then divide the seeds into different piles on the basis of color. This will give you the first step in the key, which will read somewhat as follows:

1. Seed yellow
1. Seed light brown
1. Seed dark brown
1. Seed white

It is then necessary to select some characteristic, such as size, to distinguish the different seeds of each color. For example, the seeds may be grouped into those less than  $\frac{1}{4}$  inch in length, those between  $\frac{1}{4}$  and  $\frac{1}{2}$  inch in length, and those more than  $\frac{1}{2}$  inch in length. This is added to the key. Then another characteristic is chosen, for example, shape, such as round, rectangular, triangular, or oval. These are also added to the key. The key is now as follows:

1. Seed yellow (2)
1. Seed light brown
1. Seed dark brown
1. Seed white
  2. Seed less than  $\frac{1}{4}$  inch in length (3)
  2. Seed between  $\frac{1}{4}$  and  $\frac{1}{2}$  inch in length
  2. Seed more than  $\frac{1}{2}$  inch in length
    3. Seed round (4)
    3. Seed rectangular
    3. Seed triangular
    3. Seed oval

This, of course, is not a complete key, but it indicates how a key is made. A person using the key, for example, would look at the first series of choices (1). He would see that the seed was yellow. The number (2) after the yellow seed would refer him to the next characteristic. He would then have three choices as to the size of the seed. If it was less than  $\frac{1}{4}$  inch in length, he would go to number (3), where he would have four choices. This analysis of characteristics continues until some characteristic is reached which, together with all of the preceding characteristics, exactly describes one kind of seed, and no other. Your teacher will show you how to complete the key. To test the value of your key, give it to another pupil and see if he can identify the seeds in your collection.

**Self-testing exercise 1.** Summarize the reasons for the necessity of classifying living things.

## PROBLEM 2: HOW DO SCIENTISTS CLASSIFY ANIMALS?

**STUDY SUGGESTION.** In the preceding units you have studied the different life processes and activities of living things in a general way. You have discovered that there are certain processes and activities which all living things must carry on in order to live. This problem will concern itself with the differences existing in animals. Through a study of these differences you will see how it is possible for man to classify animals.

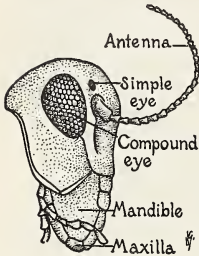


FIG. 230.

To answer this problem completely, it would be necessary to study an example of each of the different types of animals. Since this is impossible, owing to the large number of types, we shall do the next best thing: We shall study a few animals in detail and discover the differences which can be used as a basis for classification.

The aim of this problem, therefore, is not to develop the ability to describe in detail each of the animals presented, but rather to get an understanding of the method employed by the scientists to classify living things.

**What are the evidences of kinship between the grasshopper and the crayfish?** The first animal that we shall describe in answer to our problem, "How do scientists classify animals?" is the grasshopper. If you will press the outer surface of the body of a grasshopper, you will discover that it is fairly hard. This hard, horny material is called *chitin*, and the entire outer covering, or *exo-skeleton* as it is called, protects the inner organs from injury. Owing to the hardness of this outer skeleton, the grasshopper must moult, that is, shed its skin several times while it is growing to maturity.

The body of the grasshopper consists of three easily distinguishable parts, the *head*, *thorax*, and *abdomen* (Figure 231). Closer examination shows that the body is further divided into a series of segments, or *somites*. The somites in the abdomen are plainly visible. Those in the thorax

and head are not easily seen because they have been fused together or otherwise altered.

Examination of the head shows several pairs of appendages (parts joined to the main divisions of the body), each of which has several joints (Figure 230).

The antennæ are used as organs of touch, and also contain the organs of smell. The mandibles move from side to side and are used to cut and chew the food. The *maxillæ* are used to guide and hold the food. On each side of the head is a large, compound eye. This eye is composed of a number of *facets* arranged in the form of a mosaic. This arrangement enables the grasshopper to see in all directions. Strange to say, the animal also possesses simple eyes, which are arranged in a triangle in the front of the head.

The thorax bears three pairs of legs, each of which is divided into several parts. In addition to legs, the grasshopper is also provided with two pairs of wings. These wings differ from the legs in that they are not jointed. The abdomen consists of ten somites, the first of which is much larger than the others. On either side of this somite there is a fairly large oval spot consisting of a tightly stretched skin across a small depression. This apparatus is connected by a nerve to the central nervous system; it is the grasshopper's ear. It is able to respond to vibrations in the air, and thus serves as an organ of hearing.

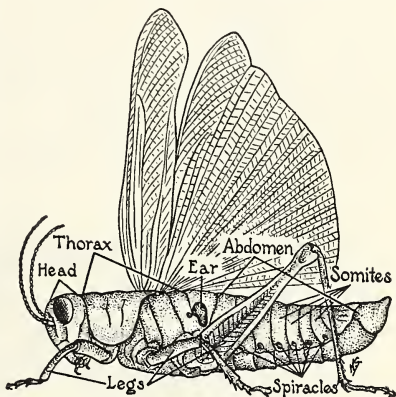


FIG. 231. External view of the grasshopper.

And now let us turn to the internal anatomy of the grasshopper. The digestive system consists of a long tube, the alimentary canal, which runs nearly straight through the body from the anterior to the posterior end (Figure 232). The alimentary canal is divided into several parts: the mouth, esophagus, crop, gizzard, stomach, and intestines. Observe, however, that the intestines of the grasshopper are only slightly coiled; they are thus markedly different from the intestines of man.

The food absorbed by the digestive tract passes into the blood. The blood, however, does not flow in definite ves-

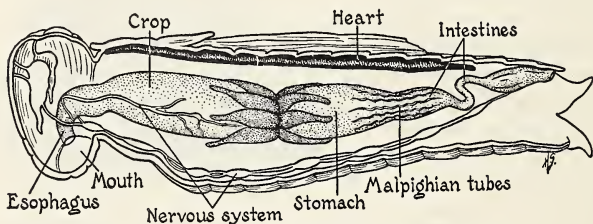


FIG. 232. Internal structure of the grasshopper.

sels, but passes through the spaces between the organs (the *sinuses*). This blood finally flows into a closed tube and enters the heart. The heart is a long, tubular vessel located in the *dorsal* part of the body. (The dorsal part is the part nearest the back of the animal.) It contains several valves, which make it possible for the blood to flow in but one direction: from the posterior to the anterior end. The heart pulsates and drives the blood to the anterior part of the body, where it passes into the body cavity and then returns to the heart at the posterior end.

Respiration is accomplished by a system of air pipes, the *tracheæ* (see page 95). These tracheæ extend to all parts of the body and are connected with several *air sacs*. The tracheæ are always open, so that a constant circulation of

air through the body is secured. Excretion of carbon dioxide takes place through the tracheæ. Water and nitrogenous wastes are excreted by the *Malpighian tubes*, which extend through the body and pour these waste materials into the intestines.

The nervous system consists of two large *ganglia* located in the head, known as the brain of the animal, and a chain of ganglia resting on the *ventral* (lower) surface of the body cavity. These ganglia contain the nerve-cell bodies from which nerves are given off to various parts of the body. All of the muscles of the body are supplied with nerves. When these muscles are stimulated by impulses from the nerves, they contract, causing movement of the body.

And now let us turn to a description of the crayfish, an animal which you probably believe to be quite different from the grasshopper. First, let us consider its external structure. Its body is covered with a hard exo-skeleton, differing from that of the grasshopper in that it contains lime. As in the case of the grasshopper, this exo-skeleton is moulted several times during the life of the animal. The body of the crayfish is divided into two general regions, the *cephalo-thorax* (the head and thorax are fused into one piece) and the abdomen, which consists of seven movable segments. The head has several pairs of appendages, the antennæ, the *antennules*, the mandibles, and two pairs of

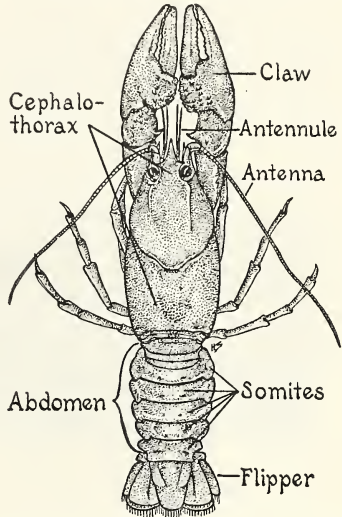


FIG. 233. External view of the crayfish.

maxillæ. Attached to the thorax are three pairs of *maxillipeds*, which aid in holding and chewing food, and a pair of large claws used for defense and food-getting. There are also four pairs of appendages used mainly for walking. On the abdomen are five pairs of *swimmerets*. The sixth and seventh segments are united to form a powerful *flipper* which is used to propel the animal backward in the water. All of the appendages are jointed.

Turning to the internal anatomy of the crayfish, we note the long, fairly straight alimentary canal, similar to that of the grasshopper. The heart is located on the dorsal surface

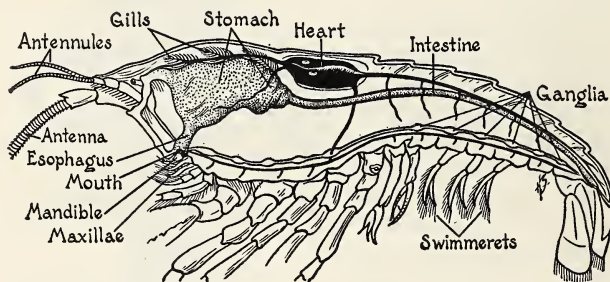


FIG. 234. Internal structure of the crayfish.

and drives the blood into the arteries, capillaries, and sinuses. Respiration is accomplished by means of gills. The nervous system consists of a chain of ganglia resting on the ventral surface of the animal.

If we compare the grasshopper with the crayfish, we find several likenesses. In each animal the body is segmented and divided into three regions. The appendages are jointed. The nervous system consists of a chain of ganglia resting on the ventral surface. The heart is located on the dorsal surface. The digestive tract extends from the anterior end to the posterior end, and is nearly a straight tube. The body is covered with a hard exo-skeleton which must be shed at

frequent intervals. It is thus evident that the two animals are built upon the same plan. Because of this similarity of structure, scientists believe that at some time in the remote past the crayfish and the grasshopper had a common ancestor; that is, they are descended from the same stock.

**SUGGESTED ACTIVITY.** Capture and chloroform some large grasshoppers. (To what part of the body will you apply the anæsthetic?) Dissect one of your specimens to observe the parts of the animal. You might also prepare a large drawing of the grasshopper to show its external parts.

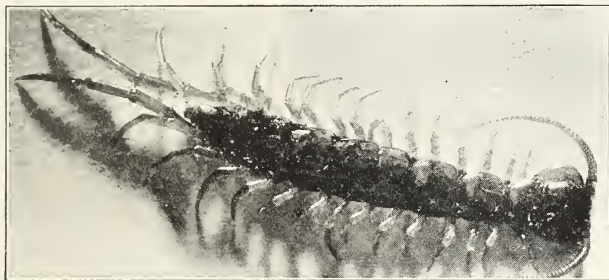


FIG. 235. With its antennæ, segmented body, and jointed legs this centipede is clearly a member of the phylum Arthropoda. (G. T. Hillman photo.)

**How does kinship determine the method of classification of living things?** Because of the kinship of the grasshopper and the crayfish, scientists have placed them in the same great group, or *phylum*. The phylum to which they belong is called *Arthropoda*, which is derived from two Greek words: “arthron,” a joint, and “pous,” a foot. All of the animals which have jointed, or hinged, appendages are placed in this phylum. There are also other characteristics, as we have seen, which are common to all members of this group. The phylum includes such animals as the lobster, crab, prawn, barnacle, honeybee, centipede, and spider. These animals are built on the same general plan as the grasshopper and the

crayfish. All animals which possess these general characteristics belong to the phylum Arthropoda.

It is not sufficient, however, for purposes of classification, to stop with the grouping of animals into phyla. It is evi-



FIG. 236. This tiny creature, the fairy shrimp, is only about one-quarter inch long, yet it has all the characteristic structures of the phylum Arthropoda that are shown by its larger relatives, the crayfish and the lobster. (G. T. Hillman photo.)

dent that there are certain characteristics which may be used to distinguish the grasshopper from the crayfish. Let us now, therefore, consider the differences in these two animals. The hardness of the exoskeleton of the grasshopper is caused by the presence of chitin; that of the crayfish is caused by lime and chitin. The body of the grasshopper is divided into three distinct regions: the head, thorax, and abdo-

men. In the crayfish the head and thorax are fused into one immovable piece. The grasshopper has one pair of antennæ; the crayfish has two pairs. The grasshopper has three pairs of legs; the crayfish has four pairs. The crayfish breathes by means of gills; the grasshopper by means of tracheæ.

These differences may be used to make a further classification of the two animals. This next division is called the *class*. Grasshoppers belong to the class *Insecta*; the crayfish are members of the class *Crustacea*. The members of the class *Crustacea*, which includes the crayfish, lobster, cyclops, sow bug, and the crab, breathe by means of gills and have two pairs of antennæ. The members of the class *Insecta* possess tracheæ, one pair of antennæ, and three pairs of legs. These differences are sufficient to place them in different classes.

**SUGGESTED ACTIVITY.** Prepare a drawing of a crayfish and of a grasshopper, and label the various external parts. Your drawings of the grasshopper and crayfish will aid you in comparing them.

If we examine certain other animals, such as flies, butterflies, moths, bees, wasps, and ants, we find that they have jointed appendages and hence belong to the phylum Arthropoda. But they also possess tracheæ, one pair of antennæ, and three pairs of legs; therefore, they are all classed as insects. It is evident that the insects named above are more nearly like each other than they are like the crayfish. Since the differences among insects are fewer than the differences between insects and



FIG. 237. Note the two pairs of wings of different size. This is an Ichneumon fly, order Hymenoptera.

crustaceans, the common ancestor of insects must have existed at a much later period than the common ancestor of both. Insects, although in the far past closely related to the crustaceans, are now more nearly related to each other.

As you already know, flies possess certain characteristics different from those of the butterflies. There are also differences between bees, ants, and grasshoppers. It is thus possible further to classify insects into another series of groups called *orders*. Differences in the structure of the wings are used as a basis for distinguishing the different orders. Some of the orders of insects are as follows:

*Order Hymenoptera (membranous wings).* Order Hymenoptera includes the ants, bees, and wasps. Four, similar, membranous wings are present, of which the front pair is the larger (Figure 237).

*Order Lepidoptera (scale wings).* This order includes moths and butterflies. The wings are covered with scales.

*Order Orthoptera (straight wings).* Among the Orthoptera are the grasshoppers, locusts, and crickets. All wings are net-veined; the fore wings are of firmer texture than the hind wings, which are folded fan-wise beneath them.

*Order Diptera (two wings).* Order Diptera includes flies and mosquitoes. The fore wings are developed, and the hind wings are reduced to stalked knobs.

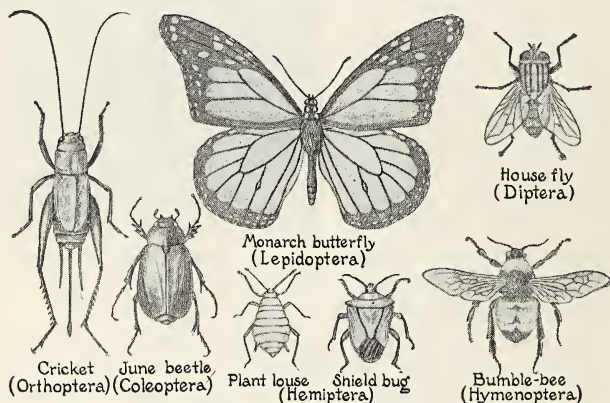


FIG. 238. Typical representatives of some of the insect orders.

*Order Hemiptera (half wings).* This order includes bugs, lice, and plant lice. These insects may or may not have wings. They all have piercing and sucking mouth parts.

*Order Coleoptera (sheath wings).* Order Coleoptera includes the beetles. Beetles have a pair of hardened wings meeting in the middle of the back and covering a second pair of wings.

As an example of further classification, let us consider the order Orthoptera. This order includes the cockroaches, the praying mantis, the walking stick, locusts, grasshoppers, and crickets. But these insects differ from each other in

several respects. On the basis of these differences, these insects are classified into *families*. For example, the family *Blattidae* includes those members of this order which have flat bodies, oval in appearance when viewed from above; which have three pairs of legs similar in form; and which run very rapidly. The cockroach is one member of this family.

The members of the family *Acrididae* have hind legs which are much stouter or longer than the middle pair and are fitted for jumping; the antennæ are shorter than the body; the *ovipositor* of the female is short and composed of four



FIG. 239. From left to right in this picture are shown the red-legged locust, the Rocky-Mountain locust, and the Carolina locust.

separate plates. You probably have seen the common red-legged locust, the Rocky-Mountain locust, and the Carolina locust, which belong to this family (Figure 239).

Since there are different kinds of locusts, it is evident that a further classification must be made. The locusts that were mentioned in the preceding paragraph are slightly different from each other; therefore they are further sub-divided into *genera*. ("Genera" is the plural of *genus*.) Furthermore, each genus may contain one or more *species*. For example, the genus *Melanoplus* includes both the red-legged locust and the Rocky-Mountain locust. They are similar in all respects with the exception that the red-legged locust has

longer wings. This difference in the length of the wings separates the two species. The red-legged locust is known as *Melanoplus femur-rubrum*, and the Rocky-Mountain locust is known as *Melanoplus spretus*. In describing a certain animal, scientists use both the generic name and the specific name. The



FIG. 240. This is the little fellow whose ponderous family history is given on page 279.

generic name comes first, and you will note that it begins with a capital letter. The name of the species comes second, and begins with a small letter. The name *Melanoplus spretus* can be applied to but one animal, the Rocky-Mountain locust. No other animal possesses the characteristics of this particular genus and species.

In an earlier part of our discussion we learned that a phylum is composed of animals having a common ancestor at some very remote time. Members of a given class, however, resemble each other more closely than they do the members of another class in the same phylum. It is therefore believed that the common ancestor of a class must have existed at a much later period than the common ancestor of the phylum. If we follow this reasoning through the orders, families, and genera, it is evident that the further down we proceed in the system of classification, the closer is the kinship. The common ancestor of the members of a given genus thus existed in comparatively recent times.

So far we have considered the main divisions made by zoölogists for the classification of animals. In actual practice it has been found necessary to divide some of the divisions into sub-divisions. To show how complex this classification is, let us examine the classification of the Southern Hudsonian red squirrel (Figure 240), set out on the next page.

*Kingdom*—Animal

*Sub-kingdom*—Metazoa (multicellular organisms)

*Phylum*—Chordata (the chordates)

*Sub-phylum*—Craniata (the vertebrates)

*Class*—Mammalia (the mammals)

*Sub-class*—Eutheria (viviparous mammals)

*Division*—Monodelphia (placental mammals)

*Section*—Unguiculata (clawed mammals)

*Order*—Rodentia (the rodents)

*Sub-order*—Sciuromorpha (squirrel-like rodents)

*Family*—Sciuridæ (woodchucks, squirrels, etc.)

*Sub-family*—Sciurinae (marmots, squirrels, chipmunks, etc.)

*Genus*—Sciurus (tree squirrels)

*Sub-genus*—Tamia sciurus (red squirrels)

*Species*—Hudsonicus (Hudsonian red squirrel)

*Sub-species*—Loquax (Southern Hudsonian red squirrel)

By means of this complex classification it is possible to trace the degree of relationship of this species to all other animals. In referring to any particular animal, it is not necessary, of course, to present a classification like that just shown. The genus and species name are sufficient to identify any particular animal for one who is familiar with the system of classification. Many trained biologists would find it difficult, if not impossible, to trace back the relationship from the generic and specific name, such as is given above, unless they consulted books of reference.

**SUGGESTED ACTIVITY.** Collect, mount, and classify various kinds of insects. Your collection should contain at least two insects from each of the orders.

**How is the kinship of living things determined?** **STUDY SUGGESTION.** It is not possible here to review all of the evidence which has helped man to classify living things. It is enough to see that the reason for believing in the kinships, as shown by the system of classification, rests upon scientific evidence.

You may wonder how the scientist discovers the kinship of different animals. Several methods of investigation are

available for this purpose. One method, of course, is to start with particular animals. For example, locusts resemble each other so closely that they must be related. They possess structures which are so alike that it would be impossible to account for the similarity that exists except by blood relationship. Blood relationship means that some time in the past there must have existed an animal, which, although not identical in structure with the locust of today, gave rise to the locusts which now exist. Similarly, locusts and bees,

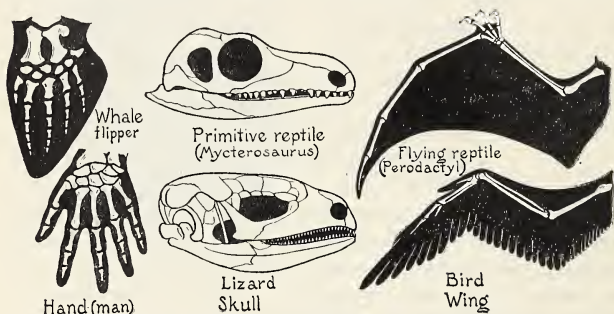


FIG. 241. Note the striking *homologies* of structure in these vertebrates of such different habits and external appearances.

while sufficiently unlike to be placed in different orders, have enough like characteristics to make it reasonable to conclude that they, too, descended from a common ancestor.

The closer the relationship, the greater the number of details in which the animals are alike. When the relationship is more remote, only a few characteristics are common to both animals, as was shown in the comparison of the crayfish and grasshopper. The closeness of relationship is thus determined by the degree to which the animals resemble each other.

Comparison of the various appendages of the crayfish and grasshopper has shown that while differing somewhat in external appearance, they are much alike in structure. Likewise, the fore limbs (arms, wings, and fore feet) of

all vertebrate animals, although differing in external appearance, are much alike in structure. A comparison of the fore limbs of birds, horses, seals, whales, bats, and apes shows that the bones correspond almost bone for bone. In the course of development through millions of years, these different animals have proceeded along different lines; hence, their external appearance after ages of development in contact with their several environments is somewhat different. The evidence seems to warrant the belief, however, that all of these structures arose in the past in a similar

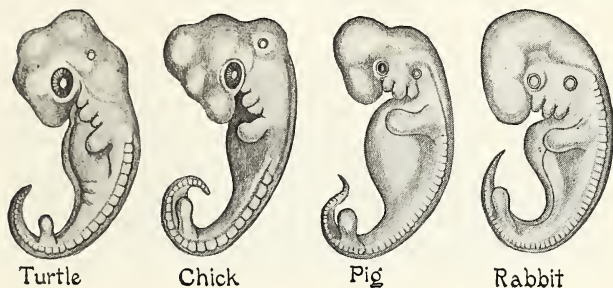


FIG. 242. In the very early stages of development embryos of different vertebrates are difficult to distinguish from each other.

way. *Homologous* is the term that scientists apply to structures which apparently have a common origin. Thus, the fore limbs of all vertebrates are homologous.

Other evidence has been accumulated through the study of the embryos of animals. In the very early stages of development, the embryos of all vertebrates are essentially alike. Different structures arise in the embryo in practically the same way. The nervous system, for example, begins with a series of ridges which are practically the same in all vertebrates. Gills are not present in adult reptiles, birds, and apes, but at one stage in the development of the embryo, gill pouches are present. This production of gill pouches in the embryos of these animals suggests a definite

relationship. Whether all of these animals could have had a common ancestor is not known, but the evidence certainly suggests that each of the animals had an ancestor that could live in water by breathing through its gills.

Classification of animals begins with a careful, detailed study of the animal. The embryological development must be studied, as well as all of the details of its adult structure. This investigation results in a scientific description of the animal which includes a description of each characteristic. Some of these characteristics will be different from those possessed by any other living thing, and will supply the basis for distinguishing that living thing from every other. Such a plant or animal will be given a specific name; that is, it receives the name of a certain species. Closely related species (that is, species with markedly similar structures) are grouped into genera. Closely related genera are grouped into families. Closely related families are grouped into orders. Closely related orders are grouped into classes. And closely related classes are grouped into phyla. Each phylum, class, order, family, and genus is set off from all other groups by the possession of certain common characteristics. Thus, through the study of structures and the homology of these structures, a system of classification based on kinship is worked out.

**What are the characteristics of the major phyla of the animal kingdom?** To understand more fully the nature of classification and the characteristics which distinguish one group of animals from another, a brief description of the important phyla of animals, together with the common names of some of the members of each group, is given here. Even from this brief description you will probably have no difficulty in classifying most of the animals of your acquaintance.

*Phylum 1. PROTOZOA.* One-celled animals, such as amœbæ, paramecia, vorticella, and euglena.

*Phylum 2. PORIFERA.* Animals with bodies perforated by numerous pores, such as the sponges. The body shows *radial symmetry*. *Symmetry* means that the body may be

divided in such a way that the two halves formed by the division will be exactly alike. An animal shows radial symmetry if it is in the form of a cylinder or cone. It can be cut from end to end at any point, and the two halves will be alike.

*Phylum 3. CœLENTERATA.* Radially symmetrical animals with a single cavity in the body, with no anus, and with tentacles and stinging cells, such as the hydra, jelly-fish, sea-anemone, and coral. (See pages 85, 198, and 207.)

*Phylum 4. PLATYHELMINTHES.* Creeping animals with bodies much flattened, usually a single cavity in the body, and no anus, such as the tapeworm, and liver fluke. The body shows *bilateral symmetry*; that is, the parts of the body



FIG. 243. This curious salt-water creature, the sea-cucumber, is a member of the phylum Echinodermata. "Echinodermata" is from two Greek words meaning "spiny-skinned sea animal." (Pinney photo.)

are so arranged that the halves on opposite sides of the body are alike. For example, the dog, horse, and ape exhibit bilateral symmetry. The anterior and posterior ends are unlike; the dorsal and ventral surfaces are unlike; but the two sides of the body are alike.

*Phylum 5. NEMATHELMINTHES.* Bilaterally symmetrical worms with long slender bodies, a digestive tract, and both mouth and anus. Includes the hookworm and trichina.

*Phylum 6. ECHINODERMATA.* Radially symmetrical animals with spiny skins, usually with five repeated divisions of the body, and with organs of locomotion operated by a water system. Includes starfishes (page 161), sea urchins, and sea-cucumbers (Figure 364).

*Phylum 7. ANNELIDA.* Bilaterally symmetrical worms with bodies divided into segments and usually with bristles or setæ for locomotion. Includes the earthworm, the sandworm, and the leech.

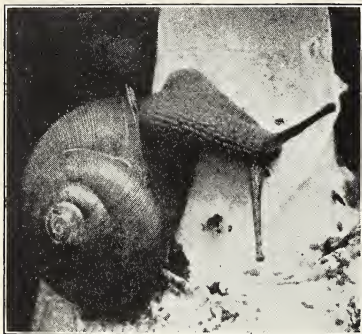


FIG. 244. The picture shows clearly the shell, muscular foot, and head of the snail.  
(Lynwood Chace © photo.)

*Phylum 8. MOLLUSCA.* Unsegmented. Usually a shell and a muscular foot. Includes snails, clams, mussels, and cuttle fish.

*Phylum 9. ARTHROPODA.* Bilaterally symmetrical animals, divided into segments, with paired, jointed appendages, and an exo-skeleton containing chitin. Includes the crayfish, the lobster, and insects.

*Phylum 10. CHORDATA.* Animals possessing either in the embryo or adult stage a cylindrical rod of cells beneath the nervous system (a *notochord*). The notochord is the forerunner of the spinal column of the vertebrate animals. This phylum includes the fishes, amphibians, reptiles, birds, and mammals.

**SUGGESTED ACTIVITY.** Make a chart, starting with the common ancestor of the crayfish and grasshopper, which will show the relationship of the different insects. You can also look up the orders, families, and genera of the crustaceans and add them to your chart. Study the chart on page 293 for suggestions.

**SUGGESTED ACTIVITY.** Examine a dog, a cat, and a rabbit. What reasons are there for believing that these animals had a common ancestor?

**Self-testing exercise 2.** Write a summary in which you show how the different divisions used in the classification of animals indicate the relationship between them.

## PROBLEM 3: HOW DO SCIENTISTS CLASSIFY PLANTS?

**STUDY SUGGESTION.** The method of classifying animals, as explained in Problem 2, is also used for the classification of plants. We shall, therefore, indicate the main groups of plants and their characteristics without explanation of the method of classification. From your study of this problem you should understand those major differences in structure which distinguish the great groups of plants.

If you will recall some of the plants which you have already studied, such as the *Pleurococcus*, bread mold, moss,

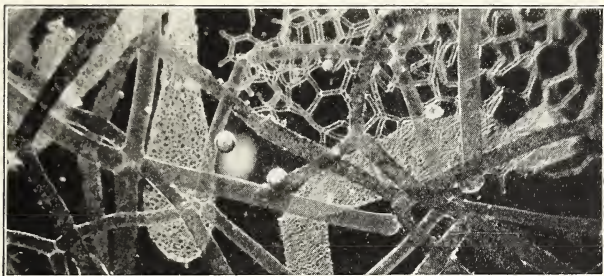


FIG. 245. Fresh-water algæ, the simplest form of plant life, as they appear under the microscope. (G. T. Hillman photo.)

and lily, you will readily remember that these plants differ in structure. Since plants differ in structure, it is thus possible to devise a scheme of classification. Plants are grouped into phyla, classes, orders, families, genera, and species in the same manner as animals. For our purposes, we shall consider only the four great phyla into which plants are grouped.

The simplest plants, you will remember, are the algæ and the fungi. These plants have no stems, roots, nor leaves in any part of their life cycle. They are thus different from all other plants; they constitute a distinct group. To this group, or phylum, the name *Thallophytes* has been given.

None of the plants belonging to this phylum possess fibrovascular bundles, nor do they produce seeds. Algæ, as a rule, are found growing in the water. Many of them are so small that they can only be seen with the aid of a microscope. Others reach a length of a hundred feet. Kelps, found along the Pacific coast of our country, are algæ. Earlier in your study of this book you have become acquainted with other thallophytes—the molds and the mushrooms.

A slightly more complex phylum of plants, the *Bryophytes*, includes the mosses and liverworts. In some external



FIG. 246. *Polytrichum juniperinum*, or hair-cap moss. The white structures that look like little flowers are the spore-bearing capsules about which you read on page 169. (L. W. Brownell photo.)

respects the mosses resemble many other common plants. This resemblance, however, is entirely external, and does not hold true in their structure. The stems and leaves are not true stems and leaves; they have no complex fibrovascular system, no spongy parenchyma, no stomata. Neither do these plants have true roots. In some respects the bryophytes resemble the thallophytes. Bryophytes, however, possess many-celled gamete-producing organs (antheridia and archegonia, page 169) which thallophytes do not possess. They thus differ in several important structural characteristics from the thallophytes and are grouped into a separate phylum.

A third great phylum, the *Pteridophytes*, includes the ferns, horsetails, and club mosses. Plants belonging to this phylum have true leaves, roots, and stems. They differ also from the bryophytes in the possession of a well-developed fibrovascular system. In their method of reproduction they resemble the mosses, as you will see in the description which follows.

The green part of the pteridophyte, which is above the ground, is really the leaf of the plant. If you will examine the under surface of the leaflets of a fern, you will usually find small brown spots extending from the surface of the leaf. These con-



FIG. 247. Field horsetail, or *Equisetum arvense*. These cone-like structures bear the spores. (L. W. Brownell photo.)

tain the sporangia, or spore holders, which, in turn, contain asexual spores. These asexual spores are scattered when ripe, and under favorable conditions they germinate. Instead of

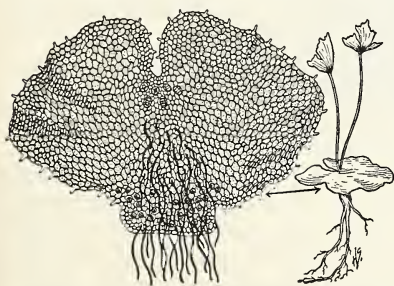


FIG. 248. Gametophyte of the fern. Just below the notch are the archegonia. Below the archegonia are the antheridia.

somewhat heart-shaped plant about the size of a clover leaflet (Figure 248). Tiny, hairlike rhizoids near the base of the plant enable it to secure water and minerals from the soil. Scattered among the rhizoids are a number of antheridia in which the sperm cells develop. Near the notch of the

plant the archegonia are produced. After fertilization, the fertilized egg grows into the roots, root-stock, and *fronds* of a mature fern plant. The pteridophytes thus resemble the mosses in their mode of reproduction, but are distinguished from the bryophytes by their possession of true leaves, stems, roots, and a well-defined fibrovascular system.



FIG. 249. Sporangia on the under side of a fern frond. (L. W. Brownell photo.)

And now we come to the fourth phylum, the *Spermatophytes*. This phylum includes all plants which bear seeds, the possession of seeds being the characteristic that distinguishes them from all other plants. How seeds are produced you already know (Unit IV). In some respects the spermatophytes resemble the pteridophytes. Both phyla possess true roots, stems, leaves, and a well-developed vascular system. The spermatophytes, however, exhibit a greater complexity in the structure of

their parts than the pteridophytes. They present the highest degree of specialization in the plant kingdom.

The spermatophytes are further classified into two sub-phyla, the *Gymnosperms* and the *Angiosperms*. The gymnosperms include such common trees as the pine, cypress, hemlock, spruce, cedar. These plants, as you know, bear cones. Pollen produced in the staminate cone pollinates and fertilizes the egg cell in the pistillate cone, producing a naked seed (Figure 250). The angiosperms include all plants which bear true flowers. Their seeds are inclosed in an ovary. The difference in the organs of reproduction is the characteristic which distinguishes the two sub-phyla.

The angiosperms are, in turn, divided into two classes, the

monocotyledons and the dicotyledons. Those plants with one cotyledon are called monocotyledons; those with two cotyledons are called dicotyledons (see page 114). Certain other characteristics also distinguish the members of these two classes. The leaves of the monocotyledons are parallel-veined, while those of the dicotyledons are net-veined (see page 33). The petals and other parts of the flower of monocotyledons are arranged in threes, while those of the dicotyledons are arranged in groups of four or five, but never three. The fibrovascular bundles of the monocotyledons are scattered throughout the stem, while those of the dicotyledons are located in a definite ring (see page 32).

About 20,000 species of monocotyledons have been identified. They include

such common plants as the wheat, corn, oat, rye, barley, bamboo, wild grasses, coco palm, date palm, hyacinth, tulip, lily, asparagus, onion, vanilla, lady's slipper, pineapple, and banana. At the present time about 120,000 species of dicotyledonous plants are known. The pea, bean, peanut, rose,



FIG. 250. At the top are two young female pine cones; at the bottom are two well-grown female cones. In the middle are the pollen-bearing male cones. (W. C. McCalla photo.)

apple, peach, pear, strawberry, cabbage, turnip, spearmint, willow, carrot, sunflower, and dandelion are members of this class of plants.

**SUGGESTED ACTIVITY.** Collect a number of the most abundant wild flowers or cultivated flowers. (Trained biologists do not pick the rarer wild flowers, even for scientific study.) Classify them as monocotyledons or dicotyledons. Further classification of these flowers may be made through the use of a key. Refer to the book lists for suggestions.



FIG. 251. Note the three-petaled flowers and the three-leafed arrangement of the monocotyledonous trillium. Are the little wood anemones monocotyledonous or dicotyledonous? Why?

**SUGGESTED ACTIVITY.** Collect various kinds of mosses to be grown in the classroom. Your specimens can be kept alive and healthy by arranging them as follows: Obtain a wooden box with dimensions approximately 3 ft. by 1½ ft. by 1 ft. At least one side

(both sides if possible) and most of the top of the box should be made of window panes. Partially fill square bread-pans with rich woods soil. Arrange your mosses in the pans, and place them in the bottom of your box. Keep your plants watered, and they will grow well. Some small ferns may be added to your collection. Experience will teach you which plants are best suited to your "Bryarium."

**SUGGESTED ACTIVITY.** Collect seeds and mount them in groups according to the plant family to which they belong. For example, the gourd family contains gourds, pumpkins, squashes, watermelons, cucumbers, cantaloupes, muskmelons, citrons, and others; while wheat, oats, barley, rye, corn, sugar cane, rice, and other grasses belong to the grass family. When you have completed your collection, prepare a table to show the like characteristics of the seeds of a given family. *Hint:* Try to think of the most scientific and original way of mounting the seeds in your collection.

**Self-testing exercise 3.** Copy the following table, inserting "Yes" or "No" in the columns.

CHARACTERISTICS OF PLANT PHYLA

| PHYLUM        | TRUE ROOTS,<br>STEMS, AND<br>LEAVES | FIBRO-<br>VASCULAR<br>BUNDLES | SEEDS |
|---------------|-------------------------------------|-------------------------------|-------|
| Thallophyte   |                                     |                               |       |
| Bryophyte     |                                     |                               |       |
| Pteridophyte  |                                     |                               |       |
| Spermatophyte |                                     |                               |       |

**Self-testing exercise 4.** Make a table like the one below, and fill out the blanks correctly.

CHARACTERISTICS OF MONOCOTYLEDONS AND DICOTYLEDONS

| CLASS         | NUMBER<br>OF<br>COTYLEDONS | LEAVES | FIBRO-<br>VASCULAR<br>BUNDLES | PARTS OF<br>FLOWERS |
|---------------|----------------------------|--------|-------------------------------|---------------------|
| Monocotyledon |                            |        |                               |                     |
| Dicotyledon   |                            |        |                               |                     |

#### PROBLEM 4: HOW DOES A SYSTEM OF CLASSIFICATION AID MAN?

**STUDY SUGGESTION.** A solution to this problem can be attained only if you have clearly understood the ideas presented in the earlier problems. If there are parts which are not clear to you, review the material presented in Problem 2. A re-reading of Problem 4 and Problem 6 of Unit V will also help you to interpret the material presented in this problem.

You have already seen that classification of living things is necessary if biologists of different nations are to work in harmony and pass on the results of their studies to other

workers in the scientific world. Now let us consider other ways in which a system of classification is useful to man.

As you have seen, the underlying principle of the system of classification is kinship. It is assumed that those living things which most nearly resemble each other are the most closely related. When animals are classified into groups on the basis of fundamental resemblances, there are, as you have learned, various degrees of relationship shown. We have explained this relationship on the basis that these animals are descendants of a common ancestral type. If the resemblance is very close, it is assumed that the common ancestral type from which the species descended lived in comparatively recent times. If the resemblance between two animals is very slight, it is assumed that they are descendants of an extremely remote ancestral type.

A chart of the probable relationships which exist in the animal kingdom is shown in Figure 252. The first animals that existed, according to this chart, were the *Protozoa*, the simple, one-celled animals. Two types of animals descended from the Protozoa, the *Porifera* (sponges) and the *Cœlenterata* (hydroids, jellyfish, etc.). No further development of the sponges took place. Two distinct types of organisms descended from the cœlenterates. One type developed into worms, and later into the arthropods and mollusks. The other type developed through a long series of changes into the vertebrates, which include fish, amphibians, reptiles, birds, and mammals, as you can see from Figure 252.

We have already considered some of the evidence which apparently shows that the present forms of life have come about through modification of earlier ancestral species. For example, the fossil records which we examined in Unit V showed that rocks laid down in different periods contain different kinds of fossils; that the oldest rocks contain no fossils of vertebrate animals; and that some species of animals have become extinct. In addition to all this, the



distribution of animals in widely separated parts of the world, such as shown by the marsupials, can be explained only by assuming that the forms of life have developed through progressive changes from simpler forms.

To the evidence as shown by the fossils, that our present living forms have evolved from those of the past, we can now add the evidence from a classification which is based on the comparative *anatomy* of living things. This classification has shown the *homologies*, or likenesses, of structure which exist among different animals. And added to this evidence is that obtained through observation of the development of embryos into mature animals. No facts are known which disprove the theory that our present forms of living things have developed from those forms which lived in the past. The theory explains satisfactorily the fossil record, the resemblances in structure of many animals, the facts of embryology, geographic distribution, and many other types of facts which have been gathered. It may safely be said that it is only by such a theory of development through the ages that the facts concerning living things can be grouped into an orderly body of knowledge.

From what you have just been studying, you can see that the efforts of scientists to classify living things have supplied a type of evidence which enables us to understand more clearly how living things have developed upon the earth.

Understanding the degree of relationship which exists between living things has helped in a practical way. For example, in planting crops man has found that certain plants thrive best in a sandy soil. This may suggest that certain near relatives, such as other plants of the same genus or family, might do well in sandy soil. This is logical, because the structures of these near relatives closely resemble each other. Had the pioneers who settled in America understood something of the nature of plants, they might have gotten suggestions from the wild plants growing here as to the crops most likely to flourish amid the environmental

conditions in this country. Wild grapes, strawberries, blackberries, and other fruits were saying, "Plant our cousins," but the pioneers did not understand.

It is possible to produce new plants and animals by cross-breeding if plants or animals closely akin are known. Luther Burbank created many new and valuable fruits through cross-breeding. Watermelons and pumpkins, cucumbers and cantaloupes, pop-corn and field corn cross-pollinate readily. The wise farmer does not grow his watermelons near his pumpkins. Neither does the orchardist who understands plant classification try to graft a peach branch on an apple tree. The peach branch will not grow; the two plants do not belong to the same genus. Apples, pears, and quinces, on the other hand, can be grafted. They all belong to the genus, *Pyrus*; that is, they bear a close relationship. An understanding of the classification of organisms is thus essential to the production of new varieties of living things.

**Self-testing exercise 5.** Explain as clearly as you can how the theory that the complex living things which exist today are descended from the simpler organisms which lived in the past makes the system of classification meaningful.

#### ADDITIONAL EXERCISES

1. Suggest some experiments which might be tried by those who do not understand how living things are classified.

2. Suggest some experiments that might be tried by biologists who understand how organisms are classified.

3. Make a survey to discover all of the kinds of trees which are growing within one block of your school or home. Make a list of the characteristics of these trees, and prepare a key which might be used by another pupil to identify all the trees within this area.

4. Visit a museum and make a study of the classification of the exhibits. For example, all of the birds are in one section, while the insects are in another section.

5. Visit a farm and observe the part classification plays in the living things that the farmer grows.

**6.** Prepare skeletons of such animals as a mouse, rat, rabbit, chicken, frog, fish, or crayfish for the biology museum. The bones can be cleaned by boiling them in a strong solution of baking soda.

**7.** If you live near a stream or lake, make a collection of mollusk shells. Classify and mount them.

**8.** A collection of fossils properly classified makes an interesting addition to the biology museum or "browsing nook."

**9.** Examine the feathers on the various parts of a bird's body. Note how each type of feather is fitted for its use. Select feathers from the head, neck, body, wings, and tail, and mount them on a cardboard. Label each type of feather. A careful description of each kind will make your collection more complete.

**10.** Collect, classify, and mount teeth of various kinds of animals. Perhaps the butcher can aid you in making your collection.

## UNIT VII

### HOW DOES MAN PROVIDE FAVORABLE CONDITIONS AND NECESSARY MATERIALS FOR LIVING THINGS?

#### PRELIMINARY EXERCISES

1. The conditions and materials necessary for plant growth are ....(a)...., ....(b)...., ....(c)...., and ....(d)....

2. The soil is composed of ....(a)...., ....(b)...., and ....(c)....

3. In caring for the soil, the farmer must ....(a)...., ....(b)...., ....(c)...., ....(d)...., and ....(e)....

4. Man provides artificial conditions for growing plants through the use of ....(a)...., ....(b)...., and ....(c)....

5. Loss in fertility of soil is made good by the use of .....

6. The plan of changing the kind of plant grown in a given field at frequent intervals is called .....

7. Barnyard manure helps the growth of plants by ....(a)...., ....(b)...., and ....(c)....

8. Write the letters of the four sub-statements which best complete the major statement.

Our forests must be conserved because—

(a) They are rapidly disappearing.

(b) Timber is used faster than it is grown.

(c) Forests help prevent floods.

(d) Forests help conserve the water supply.

(e) Forest products are of less value today than they were a hundred years ago.

(f) Forests cause destructive fires.

9. The natural resources of our country which must be conserved are ....(a)...., ....(b)...., ....(c)...., ....(d)...., and ....(e)....

10. The kinds of enemies which prey upon man's domesticated plants are ....(a)...., ....(b)...., ....(c)...., and ....(d)....

11. The kinds of enemies which prey upon man's domesticated animals are ....(a)...., ....(b)...., ....(c)...., and ....(d)....

12. Hogs may be made immune to cholera by .....

13. Cattle are often infected with ....., which is dangerous to people who drink milk.

14. Plant and animal diseases are fought by ....(a)...., ....(b)...., ....(c)...., and ....(d)....



FIG. 253. A modern seed drill operating in Western Canada (Massey-Harris Company).

## THE STORY OF UNIT VII

Our study to this point has been concerned with the major life processes and activities of living things. Through observation, experimentation, and reading we have discovered the principles underlying the use of food, growth, adjustment, relationships of living things with each other and with the environment, reproduction, and behavior. The scientist does not make the principles which govern the life processes and activities of living things; he discovers the laws of Nature through patient study and investigation. When he discovers these laws, he can make use of them to improve the living things which he selects for his use. For example, when he knows the conditions necessary for the most rapid growth of plants, he can supply these conditions.

In addition to the physical conditions necessary for growth, certain materials are required. Through experimentation man has been able to determine just what materials living things require and the proportions of each. In Units II and III you studied certain facts about the effect of the various foods upon growth and health. By applying the results of experimentation, man can improve the yield of his crops and the quality of his livestock.



FIG. 254. Man has learned to heal the wounds of trees. By bridging the badly injured part, this tree has been saved. (International Harvester photo.)

Not only is it possible to improve the yield of living things; it is also possible to produce living things which possess certain characteristics which man desires. For example, man has been able to produce corn which has a certain chemical composition and to produce wheat which requires but a short growing season and little water. Improvement along this line is largely a problem of plant and animal breeding, the principles of which will be presented in Unit VIII.

In addition to providing the necessary conditions and materials for the living things which he selects, man has also improved the conditions necessary for his own health and welfare. Through a better understanding of the nature and cause of disease he has been able to improve his physical

surroundings and thus to decrease greatly the spread of disease. This development of the science of preventive medicine has resulted in an increase of the average life-span of individuals and in the improved health and physical efficiency of mankind.

The unit which you are now to study is concerned with but one aspect of man's improvement of living things, namely, the provision of favorable conditions and necessary ma-



FIG. 255. Careful breeding and proper conditions for growth resulted in this ton-litter of pigs. "Ton-litter" is the term used to describe a litter of pigs, the total weight of which is 2000 pounds at the end of six months' growth.

terials for life. In your work on this unit it will be necessary for you to recall all or nearly all of the principles which you have studied up to this point. You will need to recall how living things obtain food, how they use food, how they grow, how they depend upon their physical surroundings, how they are dependent upon each other, how they adjust themselves to changes in the environment, and finally, how they reproduce their kind. The purpose of this unit is to help you understand how man applies the principles which he has discovered in producing plants and animals. In other words, this unit deals with scientific agriculture.

Before a farmer plants his seed, he prepares the soil for planting. Why? Many farmers cannot answer the question intelligently. They have learned how to plant through their own personal experience or through observation of others. As a result, many different methods of preparing the soil are practiced. Through experimentation, however, the best methods have been discovered. Do you know what they are? Similarly, the treatment of soils to secure high yields, methods of combating injurious insects and weeds, the best types of diet to fatten animals, and methods of conserving plant and animal products have been discovered. To learn how man has solved and is solving these problems will be your task in this unit.

### PROBLEM 1: HOW DOES MAN IMPROVE THE PHYSICAL CONDITIONS OF LIFE?

**STUDY SUGGESTION.** As you study this problem, discover the problems the farmer must solve in order to secure the maximum yield from his crops; then find how he solves these problems.

Both plants and animals can grow without attention from man. Wild life of all kinds is abundant. A greater area of our land is covered with plants which have grown wild than is covered with domesticated plants. There are also many times as many wild animals as there are tame animals. Man is in constant warfare with the wild living things of Nature. He must fight to raise the living things which are useful to him. In his struggle with the other living things he has learned that while Nature provides the necessary conditions and materials for life, he can bend these conditions and materials to his own use. He is thus able to combat the other living things successfully, and to grow the plants and animals which he needs.

**What is the nature of soil?** The growth of a crop depends upon many factors. It is influenced by rainfall, amount of sunshine, temperature, length of the growing season, and the kind and condition of the soil. Man cannot, of course,

regulate the weather or climate. He can to some extent predict what the weather may be and thus regulate other conditions to meet the daily changes in temperature and rainfall. His greatest chance of success in raising a good crop is secured, however, by providing the proper physical conditions in the soil. Let us examine the nature of soil.

**Experiment 42, Part 1. Of what is the soil composed?** (a) Obtain several samples of soil from different places, such as an open field, a meadow, timber land, or your own lawn.

(b) Take a handful of one sample of soil and rub it up in water until it forms a thin paste. Pour the paste into a fruit jar, or, better still, a tall graduate or long tube. Fill the jar with water, cover the top of it, and shake it thoroughly. Allow it to stand until the soil settles to the bottom. Can you distinguish different kinds and sizes of particles in the jar? What is the material at the bottom? Is the water clear or cloudy? Does some of the material float on the surface of the water? If so, what is it?

(c) Repeat (b), using different soils. What differences, if any, exist among them? In what ways are all of the soils alike?

The coarse material at the bottom of the jar is sand or gravel, and includes particles larger than .05 millimetre in diameter. If you will examine a few grains of sand under the microscope, you will find that they are fine particles of *quartz*. The material above the sand is *silt*, which includes particles varying from .005 m.m. to .05 m.m. in diameter. Above the silt is deposited clay, which includes particles smaller than .005 m.m. in diameter. Some of the clay particles are so small that they may float in the water and make the water turbid. The material which floats on the surface of the water is *humus*, that is, decayed plant and animal material. Most soils consist of varying amounts of these three materials. Is this statement borne out by the results you obtained in the experiment? The sources of soil are the bodies of dead plants and animals and the rocks which have been broken down or decomposed by the action of water, wind, frost, and chemicals.

A more detailed knowledge of the nature of the soil can be obtained by an extension of Experiment 66.

Experiment 42, *Part 2*. Of what is the soil composed? (a) Place some soil in a beaker. Insert a small tube in the soil down to the bottom of the beaker. Connect the tube with a funnel (Figure 256), and slowly pour in some water. Continue adding water until the water in the tube stands at the same level as the surface of the soil. The water displaces the air in the soil. The approximate amount of air in the soil is thus shown by the volume of water which must be added to drive out all of the air. It is possible to devise a method of doing this experiment so that the approximate percentage of air in the soil can be obtained. How could you do this?

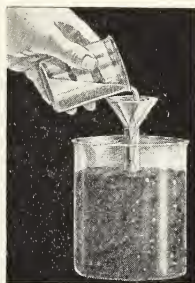


FIG. 256.

(b) Weigh a small amount of soil and place it in an evaporating dish. Heat the soil by placing it in a slow oven for several hours. Weigh the soil again, and compare its weight with the original weight. The difference in weight is due to the evaporation of the water.

(c) Weigh a small amount of the same soil used in (a), and place it in an evaporating dish or on a metal plate. Heat the soil as hot as possible. Note that the color of the soil changes as the organic material present burns. When only materials which will not burn remain, weigh the soil and compare it with its original weight. The difference in weight will be due to the loss of water and organic material. Use the results obtained in (b), and calculate the weight of the organic material in the soil.

(d) The material which does not burn represents the weight of the mineral matter in the soil. Use the results in (c), and calculate this weight. Mix the mineral matter with water, and filter it. Place the water which comes through the paper (the *filtrate*) in an evaporating dish and heat it until all of the water is driven off. Weigh the residue in the dish. The weight of this residue is the weight of the soluble materials in the soil. It is this material which is available for plant food. (It may be

present in such small quantity that your scales will not be sensitive enough to respond.)

(e) Summarize the results of this experiment in such a way that you will answer the problem of the experiment.

In the preparation of soils to receive the seed and in the proper care of the soil during the growth of the crop, the farmer or gardener faces five problems. First, he must prepare the soil

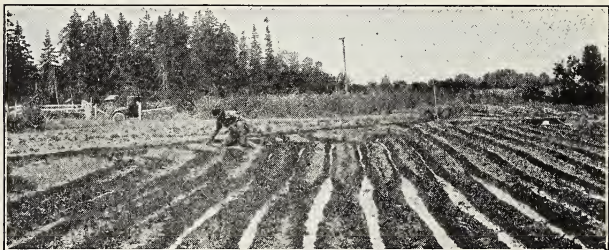


FIG. 257. In certain regions rainfall does not provide enough moisture; so man utilizes the water from rivers and lakes to irrigate his fields.

so that the proper amount of moisture may be supplied to the plants. Second, he must secure the best soil temperature for the growth of seeds and seedlings. Third, he must provide for an adequate air content in the soil. Fourth, he must prepare the soil so that the growing plants may secure food from it. Fifth, he must conserve or increase the fertility of the soil. All of these problems must be solved if the crop is to produce the maximum yield year after year.

**SUGGESTED ACTIVITY.** Obtain different kinds of soil from near your home. With the help of your teacher prepare a paper on "The Story of the Soils of Our Locality."

**How does man provide proper moisture in the soil?** Water may exist in the soil in two forms. It may fill the spaces between the particles of soil, or it may exist in the form of a thin film of water around each soil particle. In Experiment 42, Part 2, the water which was driven off from the soil was this thin film, or *capillary water*, as it is called. It

is evident that if the soil is full of water (saturated), all of the spaces between the particles of soil will be filled with water, and the air will be excluded. Capillary water, on the other hand, does not fill the spaces between the particles and thus does not exclude air. It is possible by experiment to determine if there is a certain amount of water which produces the best results in growing plants.



FIG. 258. Note how carefully the soil is cultivated in this fine plum orchard. Here there are no weeds to rob the trees of raw materials. Furthermore, this loose soil, as you will learn, helps preserve moisture and give the roots access to the air which is so important to growth.

**Experiment 43. Does the amount of water in the soil affect the growth of plants?** Plant several seeds (wheat, corn, or bean) in five beakers, each containing soil. Place the same number of seeds in each glass. Water each glass daily. Pour twenty cc. of water in beaker 1, fifteen cc. in beaker 2, ten cc. in beaker 3, five cc. in beaker 4, and two cc. in beaker 5. Note the growth of the plants in the different beakers. What do you conclude?

It is evident from the results of the experiment that the water which is most helpful to the plant is the capillary water, since it does not exclude air.

Experiments on the water requirements of plants show that an exceedingly large amount is necessary. It is estimated that five hundred pounds of water are required to produce one pound of dry matter in oats. Each ton of hay

produced on an acre requires about four inches of water. If, therefore, five tons of hay were produced on one acre, a rainfall of twenty inches would be required to produce this much hay. Part of this water is built into plant tissues, and part evaporates from the surface of the leaves.



FIG. 259. Plowing on the prairie. These great chunks of soil may dry out rather quickly, but the soil beneath them will retain its moisture longer. (International Harvester photo.)

In most regions of our country an effort must be made to conserve the rain water so that it may be available for our crops when it is needed. Only a small area of our country has enough rainfall during the growing season to supply plants with all the water they need. The most efficient method of securing the proper moisture content of the soil is by cultivation of the soil.

If the land is plowed in the fall, it has been found that more water will be present in the upper three or four feet of the soil than if the land had not been plowed. One investigator found that the difference was 2.31 per cent. There are two reasons for this difference. The plowed land allowed more water to percolate into the soil than the unplowed land, and a smaller quantity of the water which entered the soil was lost through evaporation than was the case in the unplowed land.

This brings us to the problem of how the water which sinks into the soil is made available for the plant roots.

**Experiment 44.** How is the water which sinks into the soil made available for plants? (a) Obtain several pieces of glass tubing, each about six inches long. Heat the middle of a tube in a Bunsen flame, using a flame spreader. (An alcohol lamp may be used if gas is not available.) When the glass is hot enough to bend easily, remove it from the flame and pull both ends quickly,

so that the central part of the tube is drawn into a fine tube. Break off a piece of this fine tubing about ten inches in length. Repeat this with the other tubes, and obtain tubes of different diameters. This may be accomplished by pulling the tube out to different lengths.

(b) Insert the tubes of different diameters in colored water. In which tube does the ink rise to the greatest height? What is the relation between the diameter of the tube and the height to which the ink will rise?

(c) How does this experiment answer the question of the experiment?

The force which causes the ink to rise in the glass tubes is called *capillary force*. (If you wish an explanation of capillary force, you can find it in any physics textbook.) The spaces between the particles of soil act in the same manner as the tubes in the experiment. The smaller the spaces between the particles, the higher the water will rise. The rain water which may sink many feet to the underlying rock level (Figure 260) is brought upward by this process of capillary action.

The amount of water which may be held in the soil as capillary water of course depends upon the size of the soil particles. For example, a ball one inch in diameter has a surface of 3.1416 square inches. It will thus hold a film of water of this area. One billion balls .01 inch in diameter

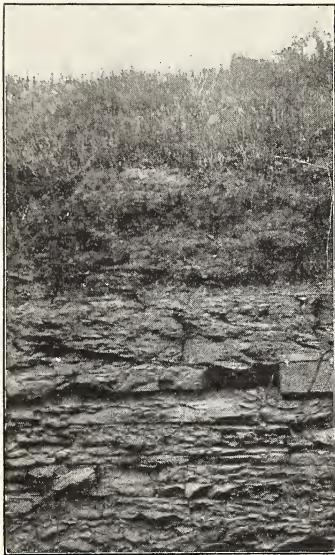


FIG. 260. This picture shows the bed rock. This rock layer may be far down, or it may be very near the surface of the earth.

may be put in the same volume as one ball one inch in diameter. The total surface of the one million balls, however, is 314.16 square inches. Thus, the smaller the particles of the soil, the greater the amount of film water they can hold. It is estimated that the surface five feet of moderately fine-grained soils can hold an equivalent of ten to twenty inches of water on the level.

One of the major problems of the farmer in caring for his soil is, therefore, to prevent the loss of the capillary water. Water is constantly being evaporated from the surface of



FIG. 261. Loosening the soil and uprooting weeds with a spring-tooth harrow in a blueberry field.

the soil. As it is evaporated, more water rises by capillary action from the lower soil levels to replace that which is lost. To conserve the moisture in the soil the farmer must prevent this evaporation. How does he do it? He breaks up the upper surface of the soil with a plow and may follow this with a harrow (Figure 261). This, of course, hastens the evaporation of water in the top layers of soil, but, by increasing the size of the spaces between the soil particles, the amount of capillary action in the upper layers is decreased. The moisture in the lower layers is thus conserved by decreasing capillary action on the surface. This layer of loose top earth is called a *dirt mulch*. Sometimes loose straw or other coarse materials are added for the same purpose.

In regions where the rainfall is scant, even greater attention must be paid to the conservation of soil moisture. The general method employed is to pulverize the surface of the soil after each rain; thus the soil retains what little water falls. In some Western states this method of retaining water is kept up through the whole season, crops being planted in alternate years. In this way the soil accumulates enough water to provide for one crop every two years. This method is generally known as *dry farming*. Dry farming does not mean that the crops can grow without water; it



FIG. 262. These men are spreading a mulch of hay over a strawberry patch.

simply means that every precaution is taken to conserve the small amount of rain that falls.

Experiment 43 showed that too much water interfered with the growth of plants by excluding the air from contact with the roots. Soil is never in perfect condition for growing crops unless it is well drained. Prolonged rainfall or overflow from streams may saturate the soil, so that the plant growth is stopped. This situation is met by artificial drainage of the soil. Surface ditches are sometimes constructed to carry off the surplus water, but constant attention is necessary to keep them from caving in and from filling with soil. The most satisfactory method is through the use of hollow tile, the water entering the tile at the ends of the tiles, which are not water-tight. Under ordinary

conditions hollow tile from three to six inches in diameter, laid to a depth of three or four feet and spaced ninety feet apart, will remove the excess water from eighty acres of land. Since a uniform slant in the tile is necessary so that the water will always flow toward the outlet, it is generally necessary to employ a drainage engineer to survey the land and determine the depth of the tile at different points.

**How does man help provide proper soil temperature for growth?** The amount of water in the soil is also important in its effect upon the temperature of the soil. Soil which contains a large quantity of water is much colder than the same soil when dry. There are two reasons why this is true. One of these reasons can be shown experimentally.

*Experiment 45.* Does water or dry soil require the greater amount of heat to raise its temperature one degree? (a) Weigh out 100 grams of soil and place it in a beaker. Take the temperature, and then heat the soil for three minutes. Observe the temperature.

(b) Weigh out 100 grams of water (100 cc.) and pour it in a beaker similar to the one used in (a). Take the temperature, and then heat the water for three minutes. Observe the temperature.

(c) Repeat (a), using 100 grams of very moist soil.

(d) Which material required the greater amount of heat to raise its temperature one degree? Why are wet soils colder than dry soils?

The other reason why wet soil is colder than dry soil is the evaporation of water from the wet soil. Heat is required to evaporate liquids, as you no doubt know. Part of this heat comes from the soil; thus its temperature is lowered.

The temperature of the soil is important in that a certain temperature is required for plant growth. The lowest temperature at which the process of growth will start in most cultivated crops is from 45° to 48° F. The best temperature for growth is from 68° to 70° F. Corn, for example, requires eleven days to germinate at a temperature of 51° F., while

it requires but three days to germinate at a temperature of 65° F. The proper temperature is necessary in order to start the physical and chemical changes which take place during growth. An increase in temperature also increases the rate of dissolving the minerals in the soil; it increases the circulation of the air in the soil; it increases the strength of osmotic pressure; and it increases the activity of the bacteria in the soil. All of these conditions aid in promoting the growth of the seed to a new plant.

Soil warmth may be controlled to some extent in two ways: Thorough preparation of the seed bed to form a dry mulch



FIG. 263. This low piece of land is known as a frost-pocket. Water will not drain off readily, and the colder air settles here. With its wet, cold soil it is an especially poor place for fruit trees, which require good drainage. (International Harvester photo.)

lessens the rate of evaporation of water from the soil. This decreases the loss of heat from the soil. The addition of barnyard manure to the soil may increase its temperature. The manure is acted upon by the microscopic organisms in the soil, which cause it to *ferment*. Fermentation is a chemical process which produces heat. A field which is heavily fertilized with farmyard manure will thus have a higher temperature than an unfertilized field. In temperate climates soils with a proper amount of moisture in them rarely become too warm. The main problem of the farmer is, therefore, that of devising methods to conserve or increase the temperature of the soil.

We have seen that cultivation of the soil tends to secure

better conditions of moisture, temperature, and circulation of air. Cultivation also aids the plant in securing raw materials. When the soil is thoroughly broken, the roots of



FIG. 264. Young trees often need pruning before planting. This young peach tree has been correctly pruned to provide for healthy growth and a balanced formation. (International Harvester photo.)

plants can force their way easily between the soil particles. This enables them to form an extensive root system. The greater the extent of the root system, the greater the number of soil particles which come in contact with the root hairs. Cultivation therefore makes available a greater supply of raw materials. Cultivation also increases the raw materials because it secures better aëration of the soil. The oxygen in the air unites with the carbon dioxide of decaying organic matter and forms carbonic acid. This acid dissolves many of the com-

pounds in the soil and makes them available to the plant for food manufacture.

The fifth problem which the farmer faces is that of maintaining the fertility of the soil. This is secured partly through cultivation, partly through the kind of crops grown, and partly through the addition of materials to the soil.

**How does man provide proper growing conditions above the soil?** The preceding paragraphs of this problem have dealt with the preparation and care of the soil to permit proper growth of the plant under the surface. Conditions above the surface of the soil may also be improved for the plant. Light, as you already know, is necessary for plant growth. If you will study carefully trees growing in a thick forest, you will observe that along the lower trunks of the large trees there are many dead or dying branches. The leaves in the tops of the trees have cut off the light from

these lower branches, with the result that sufficient energy is not available for their continued growth. This process of eliminating certain branches is called *self-pruning*.

Man assists the plants which he cultivates by artificial pruning. This cutting away of some of the branches better enables light to reach all parts of the plant. Pruning is extensively practiced in raising fruit trees (Figure 264). It not only secures better light conditions for the plant, but it also results in the production of better fruit. By pruning some of the branches, the remaining fruit buds will receive a greater amount of food and produce larger fruit. Many of the large fruits exhibited at exhibitions and fairs are produced by pruning the branches bearing small buds, thus allowing the larger and more vigorous buds a better chance to grow.

You have already learned of the importance of proper temperature for growth. When the temperature falls too low, not only is growth stopped, but the buds and blossoms of the plant may be killed. The majority of fruit blossoms, for example, are killed when the temperature falls to 30° F. or below. The Dominion Meteorological Service sends out warning when such low temperatures are expected. This enables fruit growers to protect their trees.

There are two methods of protection generally employed: One method consists of preventing the radiation of heat from the ground by covering the ground or plants with glass, cloth, heavy paper, straw mats, or smoke screens. The other method consists of adding heat to the air. A large number of small fires are lighted in the orchard (Figure 266).



FIG. 265. Pruning of the larger chrysanthemum plant resulted in the growth of one large flower instead of many small ones.

Oil, coal, wood, oil-soaked shavings, and carbon briquets are used. This method is practiced most extensively by the fruit growers in the Western states. In 1913 the lemon crop of Southern California was practically ruined by cold weather. In one orchard, however, which was protected by these small fires, the crop sold for \$734,318.07.

While man cannot control weather or climate, he can, through artificial methods, provide favorable temperatures



FIG. 266. Saving a California orange grove from frost by means of orchard heaters. Oil is commonly used as fuel.

for growing plants. It is often advantageous to start plants early in the season so that they may mature in time for market, or to grow plants out of their natural season. This can be accomplished through the use of *cold-frames*, *hotbeds*, and glass houses, or greenhouses, as they are commonly called.

The construction of a hotbed is shown in Figure 267. A pit is dug into the ground, and the bottom of the pit is filled with a layer of a foot or more of fresh horse manure. A layer of soil is placed on top of the manure, and the pit is

covered with glass. The hotbed receives heat in two ways. The manure ferments and gives off heat during the chemical change which takes place. The radiant energy from the sun passes through the glass, is absorbed by the soil, and is changed to heat which is trapped in the pit. Tomatoes, peppers, and cauliflower are often planted early in the season in hotbeds; later, when the temperature of the air outside is high enough, they are transplanted in the garden. Lettuce, radish, celery, and spinach, which mature quickly, are often planted in hotbeds and grown to maturity in them. In this

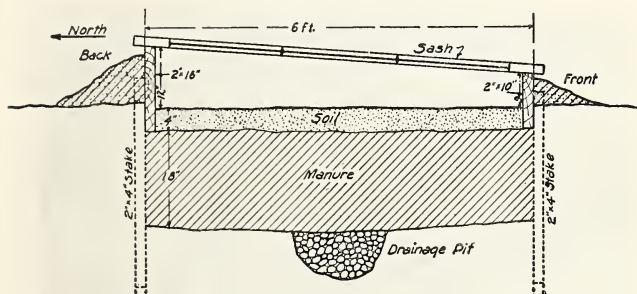


FIG. 267. Details of construction of a hotbed frame. Devices of this kind make possible the growth of various crops out-of-season.

way it is possible to produce these vegetables out-of-season and receive a high price for them.

The cold-frame differs from the hotbed in that it has no manure to develop heat. The top frame and sash are placed directly on the ground, and a few inches of planting soil are put in for a seed bed. The cold-frame is often used to harden plants which have grown in hotbeds and to protect early growing plants from snow and frost. Vegetables are also grown on a large scale in greenhouses, which are often acres in extent. By this method of forcing, vegetables may be grown out of season, and three or four crops per year may be produced. Thus, through artificial methods man

can control the physical environment of plants and can grow them to meet his needs.

**How does man provide proper physical conditions for his animals?** Man also provides the proper physical conditions for his animals. In general, this consists of providing shelter from extremes in temperature, and in keeping the shelter sanitary. With an increase in the knowledge of the habits and life processes of animals, it has been possible to design barns which are adapted to their needs. It is not possible to present in this book all the types of buildings



FIG. 268. An up-to-date dairy barn. Note the concrete floor, the clean, whitewashed walls, and the large number of windows, providing ventilation and light.

needed to house the different types of farm animals. But, by studying the problem of housing one kind of animal, we can discover how man has worked out the best methods of sheltering his domestic animals.

For our example, we shall study the housing of poultry. Before the best kind of chicken house can be designed, one must first study the habits and life processes of poultry. The following facts have been discovered by investigators: (1) The average temperature of the hen is about 106 degrees Fahrenheit. (2) The hen has no sweat glands; so most of the liquid intake is eliminated through the lungs. (3) The

hen breathes faster than man. (4) The hen requires 8278 cubic feet of air per 1000 pounds of live weight every twenty-four hours, while man requires but 2833 cubic feet under the same conditions. (5) Chickens suffer more in cold weather when the air is saturated with moisture than they do when the atmosphere is relatively dry. (6) The ability of eggs to hatch and the thickness of the eggshell are directly related to the amount of sunshine.

These facts discovered by investigators show, first, the great need of sufficient ventilation to get rid of the expired air which is highly charged with moisture, and, second, the



FIG. 269. The windows of this henhouse can be taken off in warm weather. Note the ventilators between the windows to provide fresh air in cold weather when the windows may be closed. The builder bore in mind the special needs of chickens with respect to air-supply.

need for sunshine. Chicken houses are therefore built with these requirements in mind (Figure 269). Approximately one-third of the area of one wall is left open to secure good ventilation. Since experiments have shown that the beneficial, ultra-violet rays in the sunlight are mostly absorbed by glass, these openings may be covered with muslin or burlap curtains which can be used in stormy or cold weather and taken off during the warm spring and summer months. These curtains are made of thin materials so that the air may pass through them. In order to secure the maximum amount of sunshine, the building should front to the south. A southeastern slope is preferable, with a soil of sandy loam.

Under these conditions the soil drains rapidly and is not tracked into the house.

This example of the planning of a chicken house is but one of hundreds of cases which may be described to show how man has worked out a scientific basis for providing the best physical conditions for his animals. Scientific stock-farming is the subject of continual investigation on the ex-

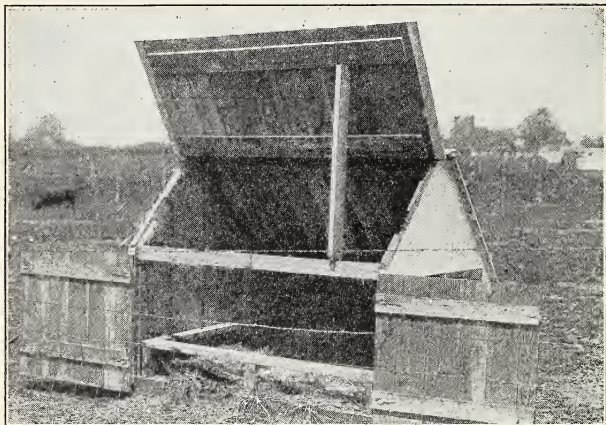


FIG. 270. This individual hog pen is so constructed that its interior can be exposed to the beneficial effects of sunlight and can be easily cleaned.

perimental farms maintained by the Dominion and Provincial Governments and by the Faculties of Agriculture in the provincial universities. Bulletins descriptive of the latest methods and findings are readily available from these sources.

**Self-testing exercise 1.** List the five problems which the farmer faces in caring for his soil. Under each problem state the methods used by the farmer in solving the problem.

**Self-testing exercise 2.** How does the problem of providing proper conditions for plants differ from that of providing proper conditions for animals?

## PROBLEM 2: HOW DOES MAN PROVIDE THE ESSENTIAL MATERIALS FOR LIVING THINGS?

**STUDY SUGGESTION.** Several questions should be kept in mind in studying this unit: How does man know what materials are essential? How does man discover if fertilizers are necessary? How does man explain the necessity of rotating crops? How does man discover what and how to feed his animals?

The materials absolutely essential for life are relatively few. All living things require food, water, and air. Under wild conditions each living thing must obtain these materials for itself. This is true even of man, as our studies of primitive man have shown. As man increased his knowledge, however, he began to modify the scheme of life which Nature had developed. Under Nature's scheme living things died or migrated when the materials necessary for their existence diminished. When living things are domesticated, the natural environment is changed to another type of environment. In order to grow the living things he wants when he wants them and where he wants them, man has been forced to supply artificially the conditions and materials necessary for growth.

**How does man help provide food materials for plants?** Under natural conditions the plants which grow in the soil die and fall to the ground. After death, decay commences, and the plant body is gradually decomposed and becomes again a part of the soil. If you will go into a forest and dig into the soil, you will find plants in all stages of decay. The soil continues to grow plants year after year because its fertility is maintained by the decay of the plants and animals that die. Under farming conditions, however, the plants grown are removed. The materials which compose the plants are drawn from the soil and the air. Since the materials are not again added to the soil through decay of dead plants, the soil loses minerals and fertility each year.

By means of a chemical analysis of plants it is possible to determine the kinds and amounts of elements that are

taken from the soil by the various farm crops. Table 9 shows the results of one such investigation.

TABLE 9. POUNDS PER ACRE OF NITROGEN AND MINERAL ELEMENTS IN AVERAGE FARM CROPS

| CROP       | NITROGEN | PHOSPHORUS | POTASSIUM | LIME  |
|------------|----------|------------|-----------|-------|
| Corn.....  | 52.6     | 6.25       | 24.10     | 18.90 |
| Oats.....  | 33.0     | 6.27       | 24.67     | 15.50 |
| Wheat..... | 29.8     | 5.20       | 18.10     | 9.89  |

It is evident from this table that continued cropping will finally remove all of the available raw materials from the soil. This has happened in a great many places in the United States. As the soil became poorer and poorer, the yield of crops became less and less, and the farms were finally abandoned because the soil was lacking in the necessary materials for plant growth.

To prevent the loss of soil fertility it is necessary to make good the loss of raw materials from the soil. This has led to the practice of *fertilizing* the soil. *Fertilizers* are materials which contain the necessary substances for plant growth, or which directly or indirectly encourage plant growth. The following table shows clearly the results of fertilizing the soil for crops of wheat, corn, and oats.

TABLE 10. INCREASED LABOR EFFICIENCY FROM USE OF FERTILIZERS INDICATED BY AVERAGE YIELDS IN LONG-TIME EXPERIMENTS ON FERTILIZED AND UNFERTILIZED PLOTS\*

| CROP       | YIELD PER ACRE |            | AVERAGE HOURS OF LABOR PER ACRE | YIELD PER HOUR OF LABOR |            | INCREASED LABOR EFFICIENCY (PER CENT) |
|------------|----------------|------------|---------------------------------|-------------------------|------------|---------------------------------------|
|            | UNFERTILIZED   | FERTILIZED |                                 | UNFERTILIZED            | FERTILIZED |                                       |
| Wheat..... | 12.5           | 30         | 11.7                            | 1.07                    | 2.53       | 140                                   |
| Wheat..... | 11.5           | 28         | 11.7                            | .98                     | 2.39       | 143                                   |
| Corn.....  | 27.2           | 46.6       | 19.0                            | 1.43                    | 2.45       | 71                                    |
| Oats.....  | 31.9           | 51.2       | 13.0                            | 2.45                    | 3.94       | 61                                    |

Two significant results are shown in Table 10: (1) The yield per acre is much greater on the fertilized plots than on the unfertilized plots; and (2) fertilizers save labor. The results indicate that fertilizing the soil is a paying proposition.

The kind and amount of fertilizer needed for a soil to produce a given crop can be determined to some extent by making a chemical analysis of the soil. The farmer who wishes information of this sort may send a sample of his soil to the Chemistry Division of the Department of Agriculture, Ottawa. Since different crops require different amounts of elements



FIG. 271. Phosphate versus no phosphate in a barley field near Lacombe. Note that the unfertilized strip in which the man is kneeling has not yet begun to head out. (Consolidated Mining and Smelting Company.)

(see Table 9), and also require different soil conditions, the kind and amount of fertilizer to use depends both on the soil and on the crop to be planted.

There are many different kinds of fertilizers. One of the most valuable is animal manure, which contains on the average ten pounds of nitrogen, six pounds of phosphorus, and twelve pounds of potassium to the ton. In addition to adding these materials to the soil, it favors the development of the bacteria which change the organic materials of the soil into soluble forms. The decay of the manure by bacteria also forms acids which help dissolve the insoluble minerals. Five tons of manure to the acre is regarded as a

light application, while twenty tons to the acre is regarded as a heavy application. Investigation has shown that it is better to apply small quantities of manure at frequent intervals than to apply a large amount and then wait a long time before another application.



FIG. 272. Root of a young bean plant. The nodules you see are very efficient at extracting nitrogen from the soil air. The nitrogen in the soil itself they leave intact.

Sometimes rye, clover, soy bean, alfalfa, and other crops are grown and then turned under the soil by plowing. This method of fertilizing is called *green manuring*, and is another means of adding humus to the soil. You remember that a supply of humus is necessary to increase the water-holding ability of the soil and to increase its temperature. If legumes are plowed under, they may add

as much as one hundred fifty pounds of nitrogen per acre.

Nitrogen is also added to the soil by the use of commercial fertilizers. Probably the commonest source of nitrogen is sodium nitrate, which is obtained from Chile. Sodium nitrate is soluble in water; hence it is immediately available for the plant roots. Ammonium sulphate is also used. Its action is slower than sodium nitrate, but it has the advantage of extending its effect over a longer period. Animal refuse of all kinds is frequently dried, ground, and sold under the name of *tankage*. The need of a nitrogen fertilizer for the soil is shown if plants grow slowly and have yellowish leaves, if the leaves are shed earlier than usual, and if the plants tend to produce seeds too early in the season. Nitrogen is necessary for the formation of protoplasm. Its effect is shown quickly in increased leaf growth, healthier

plants, and a greater vividness of color in fruit and leaves.

Phosphorus is available in bone meal, phosphate rock, and various commercial preparations. It has certain important effects upon plant growth. It increases root development and is thus valuable in dry seasons. It also causes the plant to mature more quickly, and thus aids plant growth in wet seasons. Experiments indicate that it also makes plants more resistant to disease. Indications for the need of phosphorus can sometimes be determined through an examination of the plant. If plants are stunted, if the leaves are pale green, if cereals are slow to mature, if the vegetative growth of the plant is satisfactory, but the grain yield is low, the need of phosphorus is indicated.

Potassium is necessary for the formation of chlorophyll, and is thus a requirement for starch formation. A deficiency in potassium is shown if the stalks and leaves are brittle, if leaves of fruit trees have brown patches on them, if plants are susceptible to disease, and if leaves die prematurely from the edge toward the midrib. Potassium is generally added to the soil in the form of potassium chloride, potassium sulphate, potassium carbonate, or it may be marketed under certain trade names. Potassium chloride is injurious to such crops as potatoes, sugar beets, and tobacco; for these crops potassium sulphate is usually used.

Fertilizers containing calcium have an indirect action upon the growth of plants and are frequently necessary. At times soil may become sour or acid. This frequently happens in a poorly drained soil where there is a lack of

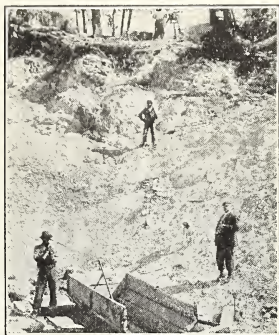


FIG. 273. Mining phosphate rock for fertilizer. Industrial by-products are a more common source of phosphorus in this country.

proper ventilation. The addition of calcium in the form of ground calcium carbonate (limestone), calcium oxide (quicklime), calcium hydroxide (slaked lime), or ashes neutralizes the acid in the soil. Whenever legumes, such as alfalfa, clover, and soy beans, are to be grown, it is essential that the soil should not be acid.

Fertilizers should not be purchased and applied to the soil in a haphazard fashion. It is possible to add too much fertilizer, which will harm the growth of plants. Unless the farmer has been trained or has had abundant experience



FIG. 274. An end-gate lime spreader at work.

with fertilizers, he would do well to secure the advice of the Division of Chemistry of the Dominion Department of Agriculture at Ottawa. Soils may be sent to the Division of Chemistry for analysis, and the exact fertilizer need can be determined. Commercial fertilizers have been analyzed, and farmers may obtain information concerning their value.

Long before scientific agriculture was possible, farmers knew that if a given crop were grown year after year in the same field, its yield would become less and less. In fact, after many years of this practice the yield proved to be only half that of a normal crop. Experimentation has shown that some system of rotating the crops from year to year must be followed to keep the yield normal. Table 11

shows the results of planting corn year after year, of planting corn followed by oats and again by corn, and of following a three-year rotation of corn, oats, and clover.

TABLE 11. CORN YIELDS. (Three-Year Averages. Bushels per Acre.)

| CROP SYSTEM                 | THIRTEEN-YEAR<br>EXPERIMENTS | TWENTY-NINE YEAR<br>EXPERIMENTS |
|-----------------------------|------------------------------|---------------------------------|
| Corn every year.....        | 35                           | 27                              |
| Corn and oats.....          | 62                           | 46                              |
| Corn, oats, and clover..... | 66                           | 58                              |

Several explanations have been advanced by scientists to account for the lessening of the yield of plants grown year after year in the same soil. Table 9, page 320, showed that different crops take different quantities of minerals from the soil. This fact is the basis for the explanation that in following one crop with another, different demands are made on the soil. For example, corn removes a great deal of nitrogen from the soil. Alfalfa and other leguminous plants do not remove nitrogen to any great extent; in fact, they may add nitrogen to the soil. Thus, if alfalfa follows corn, nitrogen compounds may enter the upper soil from lower or adjacent regions through capillary action, and from the nitrogen-fixing bacteria on the roots of the alfalfa plants. In this way the supply of nitrogen is renewed for the next corn crop. Rotation should therefore consist of using crops which make different demands upon the soil.

Some scientists believe that the roots of plants give off substances which are poisonous to the roots of the kind of plant which produced them. If the same crop is grown year after year, these poisons accumulate and thus injure the yield. If, on the other hand, a different crop is grown, there will be time for these poisons to be removed by the soil water or changed into other materials. However, this explanation is doubted by many scientists.

Experimentation has also shown that if the same crop is grown year after year, the fungi and insects which attack the plant accumulate in the soil and thus reduce the yield



FIG. 275. The summer fallow and the cultivated crop give the best preparation for a grass crop.

each year. Rotation of crops, therefore, should consist in planting crops which are not attacked by the diseases or insects of the preceding crop. The spores of the fungi lose their vitality in a few seasons; thus the same crop can be planted every few years. The theories about which you have just been reading are all based on most careful scientific investigation. It is probable that each of these theories contributes a part of the ex-

planation for the necessity of crop rotation.

**How does man provide proper food for his animals?** Man must not only provide the proper materials for the plants which he grows; he must also provide for the animals he raises. Providing food for animals is based upon the same principles as providing food for man. To determine the elements needed by animals, it is necessary to make a chemical analysis of the tissues of the animals and its products. We must know, for example, the elements present in the

body of a hen as well as those present in the egg. Not only must the foods selected contain the necessary elements, but the elements must be such that they can be used by the animal. A horse, for example, should not be fed with garbage; neither should a pig be fed with timothy hay. The digestive apparatus of these animals is not adapted to making use of these foods.

TABLE 12. POUNDS OF FOOD REQUIRED FOR DAILY RATIONS FOR EACH ONE HUNDRED POUNDS, LIVE WEIGHT

| ANIMAL                                | DESCRIPTION      | TOTAL DRY MATTER | DIGESTIBLE PROTEIN | NUTRIENTS. CARBOHYDRATES | FAT  | TOTAL | NUTRITIVE RATIO |
|---------------------------------------|------------------|------------------|--------------------|--------------------------|------|-------|-----------------|
| BEEF CATTLE BEING FATTENED FOR MARKET | Prelim. Portion  | 3.00             | 0.25               | 1.30                     | 0.05 | 1.86  | 1 to 6.5        |
|                                       | Main Period      | 3.00             | 0.30               | 1.45                     | 0.07 | 1.91  | 1 to 5.4        |
|                                       | Finishing Period | 2.60             | 0.27               | 1.50                     | 0.07 | 1.93  | 1 to 6.2        |
| MILK COWS (MILK YIELD)                | 11 lb. Daily     | 2.50             | 0.16               | 1.00                     | 0.03 | 1.23  | 1 to 6.7        |
|                                       | 22 lb. Daily     | 2.90             | 0.25               | 1.29                     | 0.05 | 1.66  | 1 to 5.7        |
| HORSES                                | Light Work       | 2.00             | 0.15               | 0.95                     | 0.04 | 1.10  | 1 to 7          |
|                                       | Moderate Work    | 2.40             | 0.20               | 1.10                     | 0.06 | 1.44  | 1 to 6.2        |
|                                       | Heavy Work       | 2.60             | 0.25               | 1.33                     | 0.08 | 1.76  | 1 to 6.0        |
| SWINE BEING FATTENED FOR MARKET       | Prelim. Portion  | 3.60             | 0.45               | 2.50                     | 0.07 | 3.11  | 1 to 5.9        |
|                                       | Main Period      | 3.20             | 0.40               | 2.40                     | 0.05 | 2.91  | 1 to 6.3        |
|                                       | Finishing Period | 2.50             | 0.27               | 1.80                     | 0.04 | 2.16  | 1 to 7.0        |

Experimentation has shown exactly what kinds of foods and what amounts of foods are necessary for each animal. It has also disclosed that animals, as well as man, need a balanced diet. Table 12 presents some figures concerning the kind and amount of food necessary for different animals.

In the last column of the table the *nutritive ratio* is given. The nutritive ratio is obtained by comparing the amount of protein contained in a ration with the amount of carbohydrates and fat. The nutritive value of the fats is changed

to that of the carbohydrates by multiplying by  $2\frac{1}{4}$ . This product is added to the nutritive value of the carbohydrates so that a single ratio is obtained. A nutritive ratio of 1 to 6.5 means that there are six and one half times as much carbohydrates as protein. Many significant facts about animal feeding can be obtained by a study of this table.

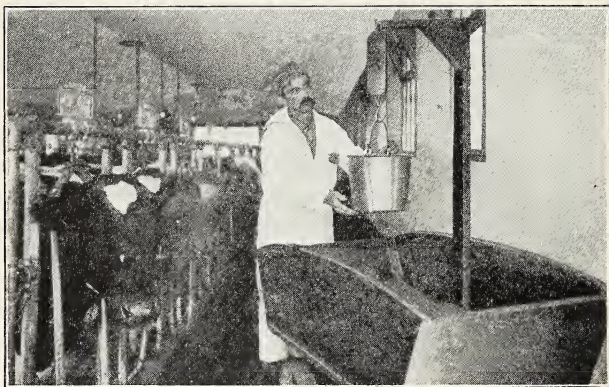


FIG. 276. The amounts as well as the kinds of food needed by animals have been determined.

**SUGGESTED ACTIVITY.** From catalogues of seed companies, nurseries, and fertilizer dealers gather data as to the elements and their proportions contained in the various fertilizers offered for sale.

**SUGGESTED ACTIVITY.** If your parents or some of your neighbors are interested in gardening, find out from them what the fertilizer needs of the soil are in your locality.

**Self-testing exercise 3.** Study Table 12 and answer the following five questions "Yes" or "No."

1. Do all animals require the same amount of food per one hundred pounds live weight?
2. Is the amount of food required by an animal always the same for that animal?
3. Is the nutritive ratio the same for all animals?
4. Is the nutritive ratio for a given animal always the same?

5. Is the proportion of carbohydrates, fats, and proteins the same for all animals?

Table 13 shows the results obtained by feeding horses on different combinations of foods. The table shows clearly that one ration causes a greater daily gain in weight than either of the other two rations. This example is typical of thousands of investigations which have been carried on

TABLE 13. AVERAGE WEIGHT AND GAIN PER HORSE ON DIFFERENT FEEDS. (18 Horses; 6 in a Lot.)

| KIND OF FOOD     |  | AV. WEIGHT<br>AT BEGINNING | AV. WEIGHT<br>AT END | AV. POUNDS<br>GAINED | AV. DAILY<br>GAIN |
|------------------|--|----------------------------|----------------------|----------------------|-------------------|
| L<br>O<br>T<br>1 | Corn.....<br>Bran.....<br>Oil Meal.....<br>Clover.....   | 1345                       | 1537                 | 192                  | 2.29              |
| L<br>O<br>T<br>2 | Corn ( $\frac{1}{2}$ ).....<br>Oats ( $\frac{1}{2}$ ).....<br>Bran.....<br>Oil Meal.....<br>Clover.....  | 1356                       | 1606                 | 250                  | 2.98              |
| L<br>O<br>T<br>3 | Corn ( $\frac{1}{2}$ ).....<br>Oats ( $\frac{1}{2}$ ).....<br>Bran.....<br>Oil Meal.....<br>Timothy..... | 1319                       | 1477                 | 158                  | 1.88              |

with different animals to determine the best ration for them. The data which have been presented should convince you that animal feeding is a scientific process based on chemical analysis of animals and foods and on experimentation in the feeding of these foods to various types of animals under varying conditions.

**Self-testing exercise 4.** Answer the questions asked in the study suggestion on page 319.

**Self-testing exercise 5.** Make a table of the symptoms in plants which indicate that there is in the soil a deficiency of lime, of nitrogen, of phosphorus, of potassium, and of humus. Use the following plan:

NEED OF FERTILIZERS AS SHOWN BY EXAMINATION OF PLANTS

| SYMPTOM                | FERTILIZER NEEDED |
|------------------------|-------------------|
| Yellowish leaves, etc. | Nitrogen, etc.    |

### PROBLEM 3: HOW DOES MAN CONSERVE MATERIALS FOR LATER USE BY LIVING THINGS?

**STUDY SUGGESTIONS.** In studying this problem keep four questions in mind: (1) Why does man need to conserve? (2) What measures has he taken to conserve? (3) What remains to be done to secure effective conservation? (4) In what ways can I assist in conservation?

Until recent years the natural resources of our country have been regarded as inexhaustible. It is easy to see how this attitude has arisen. The exploration and development of the country has opened up new coal fields, new oil fields, new forests, and new mineral resources. The supply of these products has been so far beyond the yearly need that there seemed to be no apparent end to the quantity of these materials. Today, however, we hear that our supplies of coal, oil, minerals, and lumber are diminishing so rapidly that a few generations will see their disappearance. In the face of such statements it is therefore no wonder that the need of some policy for their protection has arisen.

**How are we conserving our forests?** When the colonists first came to this country centuries ago, a great part of the land surface was covered with forests. The first settlers commonly regarded the forests as their enemy. In them lurked wild beasts and Indians, and the forests had to be cleared in order to make the land suitable for farming. This attitude toward the forest persisted throughout the

pioneer days; and, combined with the idea that the forest supply was inexhaustible, it led to the destruction of the forests. It has been estimated that more than 60 per cent of Canada's original forest stand has been burned, about 14 per cent has been cut for use, and about 25 per cent remains.

Various demands are being made on the surviving 25 per cent. During the ten years from 1926 to 1935, the average annual consumption for use of standing timber came to some two and one half billion cubic feet. Over the same period, fire destroyed each year about 267 million cubic feet of merchantable timber and the young growth of various ages on 850,000 acres. The damage caused by insects, fungi and wind-fall is not known, but is estimated at 700 million cubic feet per year. In other words, the forests of Canada are being depleted at the rate of about three and one half billion cubic feet per annum.

Now, Canada has about 600,000 square miles of timber in a growing condition. These lands, under forest management, should be capable of producing each year the ten cubic feet per acre necessary to keep pace with the annual depletion. For the time being, however, the rate of growth by no means equals the rate of consumption.

But wastefully managed or not, our forests remain an important source of wealth. In 1935, pulpwood was the most valuable single product of Canadian forest operations, comprising about one third of the total timber cut. Slightly bigger in volume, but less in value, were the lumber and firewood cuts. Charcoal, pitch, wood alcohol, turpentine, gums, dyes and many chemicals are forest products.

The forests also play an important part in the conservation of water. Rain falling on areas covered with trees is absorbed by the litter of leaves and branches on the forest floor and the humus in the soil. The water retained in this way is given out slowly through underground seepage and is thus saved to the soil. Furthermore, the forests prevent the rapid run-off of rainfall into streams, thus

helping to avoid floods. The great floods which occur from time to time result largely from the destruction of the forests. Originally about forty per cent of the watershed of the Mississippi River was covered with forests. Today less than twenty per cent of this area is forested. There is no doubt that in many regions an effective flood-control must give consideration to the maintenance of forests at the headwaters of the tributary streams. The rapid run-off of water into streams also removes many soluble minerals which are of great value to plant growth, and forms gullies which interfere with the farming of the land. The fertile

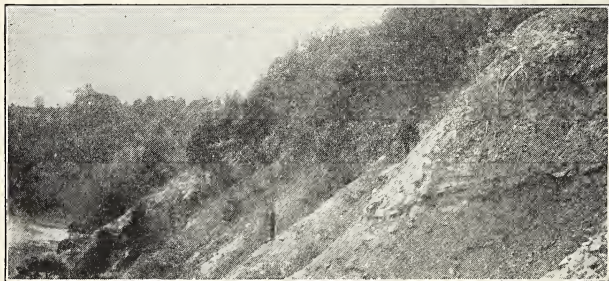


FIG. 277. The rich top soil is quickly washed away on barren sidehills like this. (G. D. Fuller photo.)

parts of the soil are thus gradually carried away and emptied into the ocean. Our forests are therefore not only of value because of the materials which they furnish us, but also because of their effect upon the water-holding capacity of the soil and the maintenance of soil fertility.

The forests have many enemies, and among them man is one of the most destructive. Fire has destroyed nearly two-thirds of Canada's original forest. More than 90 per cent of forest fires are caused by the carelessness of man. The losses in logging, in the mills, and in the manufacture of lumber products are so great that probably not more than one-fourth of the wood actually cut in the forests is utilized.

Insects also take their toll from the forest. They bore into the trees, feed upon the leaves, and cause injuries which reduce growth and which open the way for attack by fungi. Sometimes certain insects may increase very rapidly and cause an epidemic. In Quebec and New Brunswick, between 1912 and 1923, the spruce bud-worm destroyed 115 million cords of spruce and balsam pulpwood. The infestation in these provinces is now past its peak, but the insect continues to do damage in northern Ontario and Cape Breton Island.



FIG. 278. These trees have been stripped of their leaves by gypsy moths, and many of them killed.

There are also many kinds of fungi which attack trees. These fungi are spread by spores which enter the tree at points where the bark has been removed or broken. Their mycelium (see page 43) penetrates the wood of the tree, and decay of the wood follows. The loss caused by the various forms of rot and other fungous diseases is probably not much less than that caused by insects under normal conditions. To a somewhat lesser degree the forests are damaged by wind, frost, lightning, and certain of the grazing animals

which destroy the buds and bark of young trees and afford a ready means of entrance for insects and the spores of fungi. With all these enemies, it is no wonder that the forests are disappearing.

The question which arises is, therefore, what can man do to prevent the destruction of our forests and to provide for a continuous growth of forests for future use?

Up until the transfer of the natural resources of the Prairie Provinces from federal to provincial control in 1930,

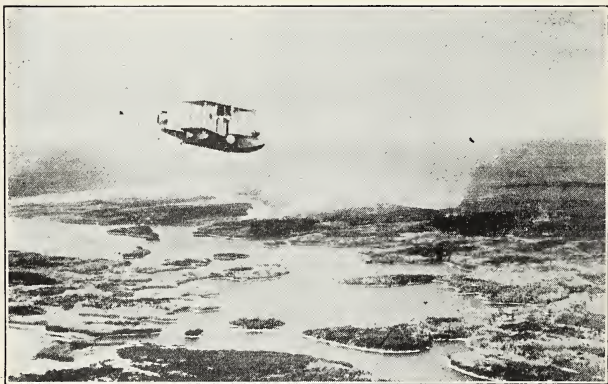


FIG. 279. Forest fire and patrolling airplane. This photograph was taken in the vicinity of The Pas, northern Manitoba. The timber shown is mostly poplar and black spruce. (Dominion Forest Service.)

the Dominion Forest Service was responsible not only for the timber stands of the National Parks, and the Forest Experiment Stations, but for those of the Prairie Provinces as well. Since 1930, however, all of the provinces, except Prince Edward Island, maintain their own Forest Services. The Dominion Forest Service has thus been left free for research in the fields of forest economics, forest protection, forest culture, and forest products. Under its supervision are the Forest Experiment Stations distributed across the Dominion and the Forest Products Laboratories at Ottawa,

Montreal and Vancouver. From such organizations we must take our lead in the work of conserving the forests we still have and of replacing the forests we have lost.

Great tracts of forest land today are unproductive because of devastating fires and destructive methods of lumbering. A large part of these lands can be made productive again through re-planting. A little is being done along this line but not enough to keep up with the quantity of timber consumed each year.

Fortunately both the federal government and the provincial governments are inclining more and more toward disposing of timber by means of licenses to cut, rather than to sell timber-lands outright. The forests of Alberta are only 7.7

per cent privately owned. We may expect, as a result, a closer supervision of cutting operations. On government lands, for instance, regulations provide for careful methods of lumbering so that the young trees, too small to be of value, are not destroyed when the larger trees are felled.

The fire hazard, which remains the forester's chief concern, has been greatly decreased by the development of new



FIG. 280. Reforestation can produce scenes of beauty like this. (Ontario Forestry Branch.)

methods. The most important departure of recent years is the use of aircraft for the detection of forest fires in their early stages. The portable gasoline-pump has been a useful addition to the fire-fighter's equipment. It delivers an effective volume and pressure of water to a point several thousand feet from the source of supply.

Methods of fire-prevention, like the methods of fire-fighting, are increasingly efficient. Legislation now provides closed seasons for brush burning, and seasons during which permits

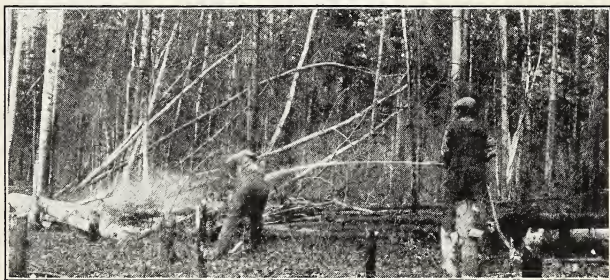


FIG. 281. Modern fire fighting. A gasoline-pressure pump makes the use of this hose possible.

are required for making fires. Popular co-operation in reducing the fire menace is due largely to the publicity given the problem by the Canadian Forestry Association.

**How are we protecting our wild life?** From a biological standpoint it has become increasingly evident that some measures must be taken to prevent the disappearance of our wild life. At one time this country was teeming with wild life of all kinds. Buffalo, antelope, elk, bear, moose, and many species of game birds were found in every suitable habitat. At the present time most of these animals have disappeared except in the few areas where they are protected.

There are several reasons for this disappearance of our wild life. In the early days thousands of animals were

trapped or slaughtered and shipped to the market. The fur-trapping industry at one time was an important source of wealth in this country. Excessive trapping and shooting for sport, made possible by the use of modern firearms and modern trapping devices, have been among the principal causes of the disappearance of wild life. The destruction of the forests, which afforded shelter for wild life, has also been a vital factor. The drainage of marshes and the pollution of streams by waste materials from factories have also taken their toll.

Methods designed to secure the conservation of wild life have been worked out by the Dominion Government through the National Parks Bureau of the Department of Mines and Resources and by the provincial governments

through certain agencies appointed for the task. In addition to maintaining the great national and provincial parks as natural habitats for wild life, these bodies deal with problems relating to the length of hunting or trapping seasons, bag limits for game, maintenance of breeding stocks, harvesting the annual surplus of wild life, facilitating the maximum production of game birds and fur-bearing animals, the diseases and parasites of wild animals, the seasonal migration of waterfowl, bird protective laws, and food habits of animals which throw light on their value or harm to man.

Over the years various laws have been passed which are designed to conserve birds, game, and fur-bearing animals.



FIG. 282. Not so many years ago great flocks of these lovely passenger pigeons darkened the sun in their flight. Now they are extinct. (Brownell photo)

By the Migratory Birds Convention Act of 1917, the Dominion of Canada assumed responsibility for the conservation of migratory birds. Co-operation with the United States has been arranged because a large proportion of these birds are reared in Canada and feed during the winter in the United States. Canada has bird sanctuaries covering an area of more than one thousand seven hundred square miles.



FIG. 283. Duck flights like this were common in the early days of our country. Now the national government and many state governments are making strenuous efforts to protect the duck from total destruction. (*Field and Stream* photo.)

The provinces for the most part have passed legislation in support of the provisions of the Migratory Birds Convention Act. To them also is entrusted responsibility for non-migratory birds, game and fur-bearing animals, and control of the inland fish resources.

The movement for conservation of our wild life is desirable not only from a recreational point of view but also from an economic standpoint. Certain of our wild animals are immensely valuable to man because of the protection which

they afford our crops and trees against the attacks of insects. You will have observed the value of birds in this respect. Fishes, toads, lizards, alligators, bats, moles, squirrels, skunks, and many other animals feed upon insects and destroy countless millions of them. On one eight-acre tract of land it was estimated that skunks destroyed 116,160 grubs. So serious has the menace of injurious insects become that one investigator has declared that "if we do not destroy the insects, they will destroy us." The protection of animals which prey upon injurious insects is thus an important precaution that we must take.

It appears therefore that, if only for selfish reasons, we should preserve the delicate "balance of life," which we discussed in Unit V. There are various complexities we must consider in going about this. For example, our Canadian beaver has a pelt of considerable value in the fur industry, but many wild life authorities believe that, left alive, he plays a role even more worth-while in our national economy. In mountain streams he is an unpaid and self-supporting water-power engineer, expert at constructing dams which impound the rush of spring waters, conserve moisture, and prevent flooding and erosion in the plains below. We must be warned by this of any short-sighted exploitation of our wild life.

Besides the passage of laws to prevent the destruction of useful wild animals, attempts are being made to increase the amount of wild life. Buffalo, elk, moose and deer find in Alberta's Buffalo and Elk Island Parks the conditions necessary for their survival and increase. In the same province the Nemiskam and Wawaskesy Parks give sanctuary to the prong-horned antelope. In recent years fur farming, or the raising of animals for furs, has been increasing. At the present time there are over 5000 fur farmers. This business is being fostered by the government through the establishment in Prince Edward Island of an experimental fox ranch to determine the best methods of raising these animals.

**How are materials conserved through preventing spoiling?**

Up to this point in our study we have been concerned with the conservation of certain of our natural resources. It is evident, however, that conservation can also be practiced with the materials which man raises. Modern science has shown the way for an enormous saving of the products which man uses for food, clothing, and shelter. Through the discovery of the causes of decay in food products, man has learned how to keep foods from spoiling; thus thousands of tons of food products each year are saved. Through the storage of food materials under proper conditions of temperature and moisture, through refrigeration and the preservation of food by chemicals and by canning, and through the conversion of plant and animal products into materials which do not deteriorate, man has created a food supply which is constant throughout the year. The treatment of fabrics with chemicals prevents their destruction by injurious insects. The treatment of wood with creosote and other preservatives prevents its decay and contributes to its length of usefulness.

Although modern science has discovered many new ways of conserving materials for later use, in actual practice an extremely large portion of the materials which could be saved are wasted. Even the advanced industrial nations, with all their modern devices, are unable, or perhaps unwilling, to prevent waste. In part, this is caused by wasteful methods of handling and manufacturing. The greater part of waste, however, may probably be charged against the individual. Either through lack of knowledge, lack of foresight, or carelessness many materials are wasted needlessly.

**Self-testing exercise 6.** Write a paragraph on each of the questions asked in the study suggestion on page 330. In the study material of this problem the data are grouped under forests, wild life, etc. It will be necessary in this exercise to group the data from these sources under the new headings presented by the questions.

#### PROBLEM 4: HOW DOES MAN PROTECT OTHER LIVING THINGS FROM INJURY AND DISEASE?

**STUDY SUGGESTION.** Before reading the material presented in this problem, make a chart to show the relationship of man to the other living things in terms of their usefulness to him. This problem presents the methods man uses to control the living things which attack the animals and plants he raises. Keep two questions in mind as you study: (1) What living things are harmful to man's crops and animals? and (2) How does man wage war on these living things?

**How is weed control effected?** When a farmer plants his crops, he must be prepared to give battle to the other living things which check or destroy the growth of the plants he is attempting to raise. In the struggle for existence between his plants and the other living things which try to obtain a foothold in the same area, he must utilize all of the weapons which science has forged. Even then he is frequently the loser in the struggle.

In the first place, when the farmer plants his seeds, the soil already contains thousands of seeds which may germinate and produce plants when the proper conditions are present. Several investigations have shown that there is almost an unbelievable number of seeds in the soil. In a field that was intended to be planted with spring grain, the same crop having been sown for four successive seasons, Korsmo, a Russian scientist, found that there were 33,574 weed seeds on one square metre of ground.



FIG. 284. Banks of weeds like this leave little chance for the plants that man needs. (L. W. Brownell photo.)

Similarly a field near Lacombe which had been seeded to oats and barley for nine years showed the presence of some 20,240 weed seeds to the square yard. Weeds, then, are one of the farmer's most serious problems. They rob the

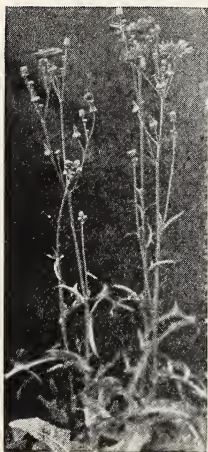


FIG. 285. Members of the thistle family are widespread plant pests.

soil of moisture and plant food materials, thus aggravating the effects of drought; they compete with crop plants for room and light, proportionately reducing the yield; they reduce the value of land and the quality and price of grain and forage crops; their eradication is costly and diverts the farmer's time and labor from more useful ends. Some weeds are harmful either to stock or to their products; others attract injurious insects and harbor fungous diseases.

Many of the troublesome weeds, such as the prickly lettuce, common plantain, tumble weed, spring amaranth, ragweed, foxtail grass, stinkweed, wild oats, and false flax, are annual plants. Since these plants die each year and reproduce the next year from their seeds, the most evident method of decreasing the next year's yield is to prevent the production of seed. This is generally accomplished by plowing and harrowing before the weeds have come to maturity. Annual weeds thrive best in soil that has been broken but not sown with a crop. Broken land (land which has been plowed), therefore, should not be permitted to lie idle, because the weeds of near-by fields will distribute their seeds to this soil where they can so easily take root.

Perennial weeds, such as the Canada thistle, sheep sorrel, toad flax, quack grass, and Johnson grass reproduce not only by seeds but also by underground stems or runners. They

are thus very difficult to eradicate, because the underground portion must be killed as well as seed formation prevented. Some of them, like the quack grass, can regenerate fresh shoots, as you learned in Unit IV. Several methods of control have been tried and found fairly successful. On a small area of land it is possible to dig up and completely remove roots, rootstocks, and bulbs. This, of course, is impossible upon large areas. The roots may be starved by preventing the growth of any green part above the ground. This is accomplished by covering small patches of weeds with straw and by persistent cultivation of fields. Salt, kerosene, or strong acids, when applied to freshly cut roots, destroy them for some distance, but this method is too expensive for large areas of land. Dense crops of hemp, buckwheat, clover, cowpeas, or millet are sometimes planted to smother the plants and exclude the light. The growing of such a smother crop for two or three years in succession has almost completely eradicated couch grass. Grain crops compete more successfully with weeds in proportion as the rate of seeding is increased. The amount of mustard in a crop of barley was reduced from 239 pounds to 91 pounds of seed per acre by increasing the rate of seeding from one bushel to three bushels per acre.

One source of weed distribution has been greatly decreased in recent years, namely, the sowing of weed seeds by the farmer himself. Analysis of one sample of clover seed weighing 19.4 ounces showed that it contained 8478 weed seeds, representing 39 different species. Studies of this sort were made a few years ago, and the result has been the establishment of seed-testing laboratories and the passage of laws which regulate the purity of seeds offered for sale. These laboratories analyze seed samples and condemn those which show too high a proportion of weed seeds.

It should be the duty of every citizen to coöperate in weed control. Despite all of the measures that have been taken to control weeds, they still are a serious menace to the farmer.

### What methods are used to destroy injurious insects?

In addition to the weeds which compete with the plants he cultivates, the farmer must also wage war against insects which use his plants for food. It is estimated that in Canada the yearly damage done to trees and crops by insects amounts to \$200,000,000, and in the United States the annual loss is estimated at \$2,000,000,000.



FIG. 286. This band of sticky paper prevents these climbing caterpillars from reaching the foliage of the tree. (International Harvester photo.)

In grain growing districts in Canada insects represent the greatest controllable factor affecting crop production. In the Prairie Provinces, for example, in a given year millions of acres may be affected by grasshoppers, and several hundred thousand acres by the pale western cutworm or wheat-stem saw-fly. In Eastern Canada potato growers and orchard men know the destructive nature of the Colorado potato beetle and the codling moth. East and west, who has not seen a forest of trees de-

nuded of foliage by the tent caterpillar?

Control of the pests depends first on a study of their habits and development. To this end Government entomologists have made careful research into the feeding habits and the different steps through which the insects pass in attaining maturity. It has been found that the damage is caused usually in certain stages of development, and, in some cases, that the insect feeds on only certain portions of the plant.

For example, the cutworm moth appears from its pupa about August 1st, and immediately starts laying eggs. Cul-

tivation of summer fallow, therefore, should be completed before August 1st, so that the surface of the soil may have time to become encrusted, which will prevent the moth from laying her eggs in the soft earth.

An example of the relation between study and control may be seen in methods of wheat-stem saw-fly prevention. This black, wasp-like insect that has been so damaging to western crops, lays its tiny eggs during the last two weeks of June, on the stems of grains and grasses just above the top joint. When the eggs hatch, in three or four days, the larvæ eat their way down through the stem of the plant, until just before harvest time they reach the roots, saw off the stem above them, seal over the trunk of the stalk and remain there during the winter months.

The most effective means of control is to sow brome grass or early oats as a trap around the fields



FIG. 287. A saw-fly, enlarged.



FIG. 288. The western wheat-stem saw-fly: (1) straw cut open to show tunneling of larva; (2) plant severed near ground; (3) stub with larva in winter position; (4) stem showing characteristic resting position of saw-fly; (5) female saw-fly; (6) mature larva. (Illustrations about one-half natural size.)  
(Grain Growers' Guide.)

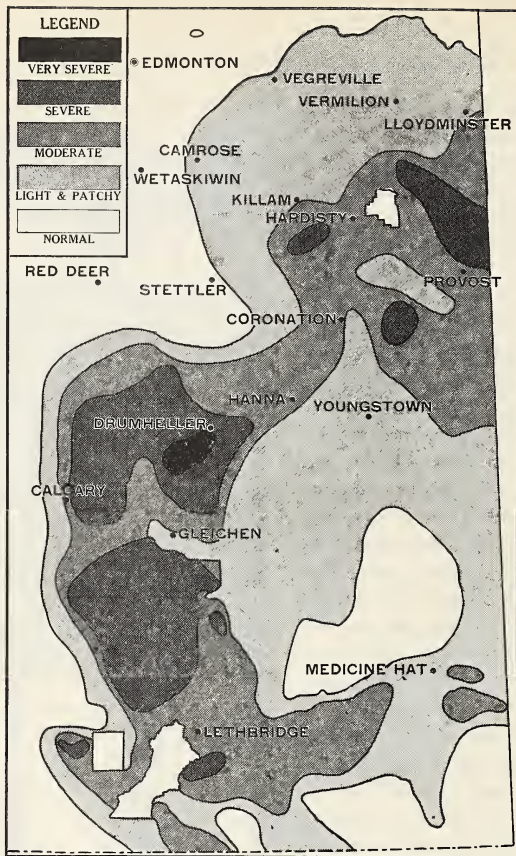


FIG. 289. This map indicates where grasshopper outbreaks may be expected in Alberta. The Alberta and Dominion Departments of Agriculture make these suggestions: (1) Every few days after May 10 examine carefully all roadsides, headlands, and weedy or abandoned fields. Report discovery of hoppers immediately to the Municipal Secretary. (2) Do not sow stubble land. If absolutely necessary to seed stubble, it should be ploughed deeply. (3) Land to be summer-fallowed should be cultivated shallowly early in the spring to bring egg pods to the surface where wind and rain may destroy them. (4) Plough four-rod guard strips around all stubble fields. Cultivate such fields from the outside towards the centre, and poison the hoppers on the centre strip. SPREAD POISONED bait while the SUN SHINES. (Adapted from an official poster forecast of the areas of grasshopper infestation in 1939.)

to be protected. The moths then lay their eggs in the brome or oats, and as brome grass and oats are not good food for the larvæ, they are killed. Rotation of oats with wheat is also a preventive of serious damage, as the oat crop lessens the infestation. Also, an infested wheat crop should be cut on the green side before the larvæ saw off the stems.

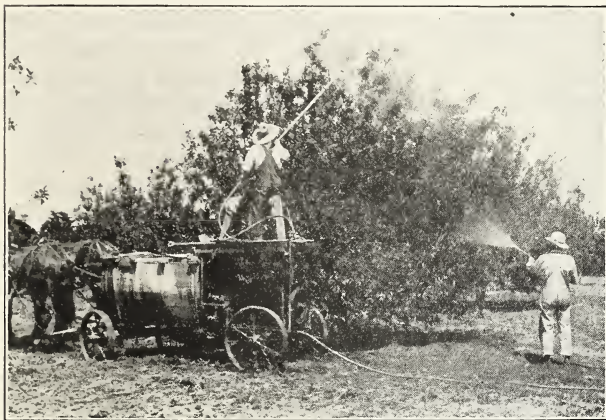


FIG. 290. Spraying fruit trees with insect poison

Grasshoppers, perennial plagues in ancient times, lay their eggs in the fall to hatch in early May and June. In Western Canada, where summer fallowing is practised, clean fallow, free from weeds, is usually also free from grasshopper eggs in the fall. On cropped ground, deep fall ploughing buries the eggs so deeply that young grasshoppers cannot reach the surface of the soil in the spring. Poisoned bait is frequently used to kill grasshoppers. A common recipe consists of fifty pounds each of bran and sawdust mixed with about twelve gallons of a solution of salt and water, sweetened with a couple of quarts of molasses and rendered deadly with five pounds of white arsenic or Paris green. The mixture is spread thinly—about twenty pounds of wet bait per acre.

Whether the means of insect control be poison, soil cultivation, crop rotation, the sowing of special crops, or whatever it may be, community coöperation is essential, so that one farm freed from a pest may not be infected by insects from a neighboring farm where control measures have not been taken. To make coöperation possible Government Bureaus, through research and continued study, are able, in many cases, to forecast an infestation of a particular insect. For example, the map on page 346 was copied from one published in March 1939, to show the forecast of the appearance of grasshoppers in Alberta the following summer. Community and individual efforts, particularly in the sections of the province marked "very severe" and "severe," would go far toward decreasing the expected damage.

A second class of poisons are called contact-poisons. They kill the insect through contact, and are generally used with sucking insects. Nicotine, soap, oil emulsions, sulphur preparations, and kerosene emulsions, are commonly used for this purpose. Products that have been stored are usually protected by fumigants in gaseous form; these enter the tracheæ of the insect and kill it.

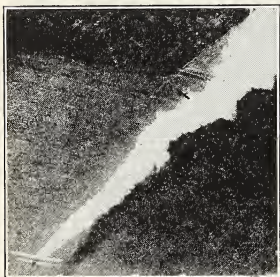


FIG. 291. Dusting a field of cotton by airplane to destroy the boll weevil. (U. S. Bureau of Entomology.)

The protection of plants by chemicals is a task for an expert, since many factors must be considered. First, the kind of insect causing the damage must be determined. This is quite often a difficult task. Second, the kind of spray to use and a satisfactory method of application must be determined. In addition to these factors, the cost of the process must be calculated, and the probable return in added crop as a result of the treatment must be determined. Table 14 shows the valuable results of spraying obtained on three farms.

TABLE 14. SUMMARY OF RESULTS FROM SPRAYING FRUIT TREES

| TREATMENT      | DISEASE<br>INJURY | INSECT<br>INJURY | SPRAY<br>INJURY | UNBLEMISHED<br>FRUIT |
|----------------|-------------------|------------------|-----------------|----------------------|
| Sprayed.....   | 1.56%             | 6.97%            | 1.05%           | 88.5%                |
| Unsprayed..... | 20.4%             | 46.7%            | 0%              | 31.0%                |

### How does man fight disease in his plants and animals?

The first column in Table 14 shows the decrease in injury by disease as a result of spraying. This brings us to another great group of plant enemies: the rots, scabs, rusts, smuts, and other fungi which infest plants. Fungous diseases each year inflict heavy damage on plant life. The common method of control is by chemical treatment.

The progress made and methods employed by man in the control of plant disease can be illustrated by the story of the barberry bush and its relation to the rusts of small grains. Stem rust has been a destructive disease for thousands of years. The first relationship between the barberry and rust was noted in the 17th century, when farmers discovered that rust was always very common near barberry bushes, and that as the distance increased, the rust was less severe. No explanation was possible at this time. In 1865 DeBary, a German scientist, discovered the stages in the life cycle of rust. The rust which grew on the barberry was one stage in the development of the grain rust. The spores from the barberry rust were scattered by the wind to the stems and leaves of the grains, where they reproduced and infected the plants. As a result of DeBary's discovery, a campaign for the destruction of barberry bushes has been instituted.

Canada may profit from the campaign of destruction waged on the barberry bush in the United States. While there are very few plants of the barberry in Western Canada, outbreaks of rust still occur. And, since the rust spores may travel in the air hundreds of miles, there seems little doubt that the rust infections in Western Canada in 1935 were produced by spores brought by currents of air from Minnesota and South Dakota.

In the United States, surveys have been conducted to locate barberry bushes and destroy them. The State of Wisconsin, for example, has destroyed over five million barberry bushes since its campaign started. The work is still going on, and there is every reason to believe that through

the destruction of barberry bushes the fight against rust will ultimately end in a victory for man.

But our Canadian laboratories for plant study have not been content to wait and hope that rust damage will disappear with the destruction of the barberry. The full urgency of the problem was first felt by Canadian farmers in 1916, when an unusually severe attack of wheat stem rust devastated the fields of Manitoba and eastern Saskatchewan at a cost of millions. Improved methods of plant breeding, which you will find discussed in Unit 8, seemed to offer the chance of creating a variety of wheat that would resist the



FIG. 292. Illustrating how new wheat varieties reduce losses due to plant diseases. Apex (right) and Marquis (left) under severe drought conditions in 1935 in southeast Saskatchewan.

ravages of rust. It became a question, not of checking the disease at its source, but of growing wheat with a special immunity against it. The Dominion Rust Research Laboratory was accordingly established at Winnipeg. Hundreds of rust-resistant wheats have been produced, of which the most promising have been Renown, Apex, and Thatcher. The spe-

cial rust-resisting quality of the University of Saskatchewan's Apex is shown in Figure 292. Note the cleanness of head and stem as compared with the Marquis specimens.

Farm animals also suffer from the attacks of insects and other parasitic animals. Lice, mites, and ticks of many different varieties prey upon pigs, cows, horses, sheep, and chickens. These pests weaken the resistance of animals to disease and may interfere with the proper growth of the animal or its output.

Chickens, for example, often become infested with the common chicken mite. It is a bloodsucker, and remains on the body of the host until it is gorged with blood; then it returns to its hiding place in cracks, refuse, and other obscure places. Setting hens often leave their nests as a result of infestation, and decrease in chicken production usually results. The common remedy is to disinfect the interior fixtures and all crevices and cracks with some solution such as kerosene emulsion, or crude petroleum, which will destroy the mites. This is usually followed by a coat of whitewash which fills up many of the crevices. Chickens are also infested with several varieties of lice. When this type of infestation occurs, the birds are dipped into a solution of sodium fluoride, which is destructive to these insects.

In general, the same measures are employed in destroying insect pests and other parasites of other kinds of animals. The most important preventive measures which can be taken are as follows: (1) Keep the living quarters of animals in a sanitary condition. (2) Quarantine all sick animals at the earliest sign of illness. (3) Quarantine (for several weeks) any new animals that may be purchased, and watch them for signs of infestation and disease before they are allowed to run with the other animals.

In addition to the infestations of insects and parasites, animals are also subject to many kinds of diseases. One of the most costly diseases has been that of hog cholera. Animals infected with this malady and slaughtered under

government supervision in 1914 numbered 34,779. The compensation paid by the Dominion for these animals amounted to \$196,981. An epidemic of about one third these proportions occurred in 1928. However, ten years later, the report of the Veterinary Director General for the 1937-38 season shows the number of hogs slaughtered for this disease cut to exactly five. The improvement is due in part to the preventive treatment worked out by Marion Dorest.

Briefly, the preventive treatment consists in giving the hog a dose of *serum* and a dose of *virus*. The serum is prepared from the blood of hogs that are *immune* to cholera. that is, hogs that cannot contract the disease. These immune hogs are injected with the blood of hogs sick with the cholera. This blood contains the germ which causes the disease. The result is the production of *antibodies* (substances that fight disease germs) in the body of the immune hog. The serum is prepared from the blood of these hogs, and contains these antibodies.

The serum treatment alone will protect the hog from cholera for some time, but it is not permanent. For a more permanent preventive it is necessary to *inoculate* the hog with the blood of an animal sick from the disease. This blood, or virus, contains live cholera germs. These germs cause a reaction in the hog which establishes an immunity similar to that produced in hogs that recover from a natural attack of the disease. Enough serum must be given to neutralize the effect of the germs and permit the production of an oversupply of the antibodies that fight the disease germs.

But problems continue to crop up. Concern is now being felt in the Prairie Provinces over an outbreak in epidemic form of encephalomyelitis, a disease of horses that manifests itself by nervous symptoms. A summary compiled from questionnaire forms shows that on sixty-five farms 107 out of 670 horses developed the disease with a mortality rate of approximately 6 per cent. The Animal Diseases Research

Institute has succeeded in isolating the virus of equine encephalomyelitis and so has completed the initial stages in working out a preventive treatment. The serum-virus method, outlined above in connection with hog cholera, is reported to have given good results. But until final data is available, certain measures may be taken to avert the spread of the disease. Since it is known that the infection may be transmitted by insects, the Department of Agriculture recommends the isolation of affected horses in screened quarters, or where this is not possible, the use of sprays



FIG. 293. Inoculating a hog with cholera serum.

to prevent insect biting, and finally the stabling of horses not at work during the insect season.

Another disease which results in millions of dollars of loss each year is tuberculosis. This disease, however, is slowly being eradicated. A number of years ago a new test was discovered, which may be used to determine whether or not an animal has tuberculosis. This test, called the *tuberculin* test, is administered in several ways. One method is to inject the tuberculin underneath the skin. If the animal has tuberculosis, its temperature will rise in a few hours and then subside (Figures 294 and 295).

In the course of fifty years' official testing for bovine tuberculosis, the government has worked out three systems

or “policies” of control. The Accredited Herd Plan was designed to protect pure-bred cattle. An accredited herd is one which has passed two clean tests with an interval of a year. Under this plan reactors—those animals which exhibit the temperature rise in the tuberculin test—are

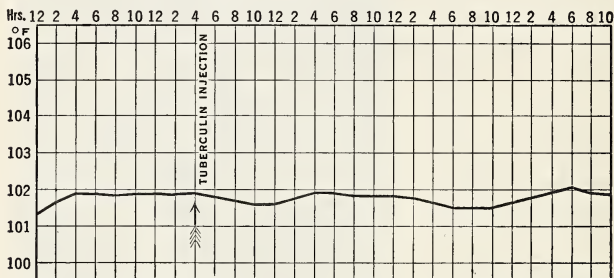


FIG. 294. The temperature curve of a healthy cow which has been given the tuberculin injection.

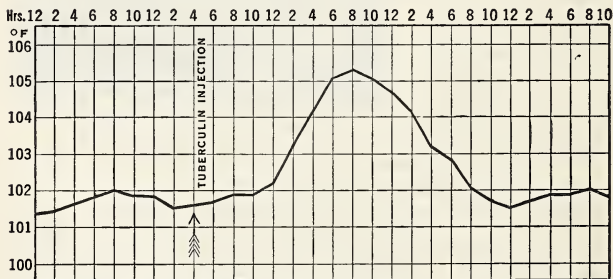


FIG. 295. The temperature curve of a tubercular cow which has been given the tuberculin injection.

slaughtered, the owners being compensated by the government. On March 31, 1939 there were some eight thousand fully accredited herds. The Supervised Herd Plan accommodates herds of grade cattle not qualifying for care under the Accredited Herd Plan. The procedures are the same

except that under the Supervised Herd Plan no compensation is paid for the reactors slaughtered. There were 49,000 herds of cattle under the plan in 1938. The Restricted Area Plan is a device for eliminating tuberculosis piece-meal by districts. At the request of two-thirds of the stock owners in a given area the federal Minister of Agriculture will gazette that area for special attention. Since testing is compulsory, compensation is paid for animals slaughtered, and to keep the area "clean," rigid restrictions are placed on the importation of outside cattle. These three control policies have resulted in a decrease in tuberculosis infection from 5% in 1928 to 3% in 1938.

It is hoped that a recently developed method of vaccinating cattle will make them immune to tuberculosis just as human beings can be made immune to it. The practice is to vaccinate the calves within two weeks after birth and once each year thereafter. Results so far have been very satisfactory, but the method has not been in use long enough as yet to make scientists sure that all cattle can be made immune in this way.

Experimentation has shown that tuberculosis in cattle can be transmitted to human beings in the meat and also in the milk. Such tuberculosis does not attack the lungs of human beings, but, instead, it affects certain glands and the bones. Children are particularly susceptible to it. The problem is therefore an important one for all to consider. A great many of our municipalities require that the milk sold in the city be pasteurized (heated to a temperature of from 131° to 158°) or be from herds which the tuberculin test has shown to be healthy. The government has inspectors in all of the large meat-packing plants to inspect the meat for tuberculosis. Their findings are in support of our other evidence showing that the incidence of the disease has been much decreased. The campaign for the eradication of tuberculosis in cattle is thus producing results, and this disease may ultimately be eliminated.

**Self-testing exercise 7.** Write a two-page answer to the question of this problem. Your answer should be in the form of a summary of the methods employed by man in protecting his domesticated plants and animals.

#### ADDITIONAL EXERCISES

1. Why does the formation of a crust on the surface of the soil in the hot summer months increase the rate of evaporation from the soil?

2. How does the cultivation of the top layer of the soil break the lines of capillarity?

3. Refer to a physics textbook and write an explanation of capillary force.

4. Why does the addition of too much fertilizer to the soil sometimes kill the plant?

5. Make a list of the practices mentioned in this unit which favor more rapid growth of plants or animals.

6. Assume that a farmer intended to raise wheat. If he proceeded in a scientific manner, what steps would he take to insure a good crop? Explain the necessity of each step.

7. How is the soil conserved under natural conditions?

8. What laws does your province have to conserve its natural resources and wild life?

9. Find out all you can about the pruning of shrubs that are used for decorative purposes around houses. Are there different times for pruning different kinds of shrubs? How should the cut be made, and why? What shrubs are particularly adapted to shaping?

10. At what time of day is it best to water the garden and the lawn? Why?

11. Find out whether anything is being done by your community to protect trees. The men in charge of your parks can probably give you some information. Perhaps certain individuals in your town or city have called in tree experts to save trees in their yards.

## UNIT VIII

### HOW ARE LIVING THINGS IMPROVED?

#### PRELIMINARY EXERCISES

1. Write the letters (a) to (e) in a column. Mark with a plus sign the letters of those statements which correctly complete the main statement.

The world of living things today is different from the world of living things several million years ago in that—

(a) There are certain kinds of living things today which did not exist several million years ago.

(b) There existed several million years ago certain living things which do not exist today.

(c) Man has changed the characteristics of some living things so that they differ from their early ancestors.

(d) Man has improved many living things for his own use.

(e) Man has domesticated certain plants and animals and has destroyed others.

2. Write the letters (a) to (n) in a column. Then write "True" or "False" after each letter according to whether the statement so lettered is correct or incorrect.

(a) Living things tend to resemble their parents.

(b) Living things inherit characteristics from their parents.

(c) Living things are exactly like their parents.

(d) Modifications in structure which occur during the life of an individual are transmitted to the offspring.

(e) It is impossible for new species to come into existence.

(f) Plants and animals always breed true.

(g) Plants can be improved by selecting the best plants of each generation and using their seed for the next crop.

(h) Animals possess definite characteristics which may be propagated through selection.

(i) Animals and plants may be improved through cross-breeding.

(j) New types of living things are produced through variation.

(k) The environment produces changes in living things.

(l) Animals belonging to different families can be crossed to produce new species.

(m) Pure-bred animals produce better offspring than mongrel types of animals.

(n) Man has modified natural laws to effect changes in living things which will be beneficial to him.

### THE STORY OF UNIT VIII

If you ask someone to tell you about the changes that have taken place in the world during the past one thousand years, his answer will generally consist of an enumeration of

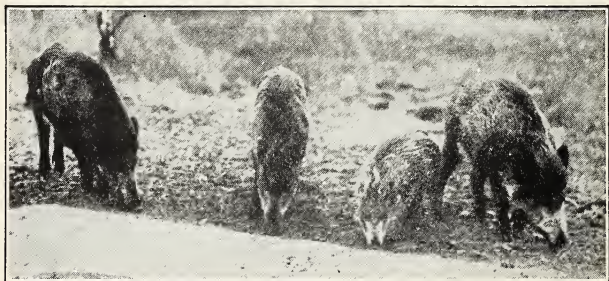


FIG. 296. European wild hogs. From the long-nosed, long-legged, and slender wild hogs of Europe and Asia have been developed the fat, short-legged "porkers" that are now such an important source of food. (Underwood and Underwood photo.)

the inventions and discoveries by which man has harnessed the physical forces of nature. Rarely, if ever, will the answer include a statement of the changes which have taken place in the living things of our world. But if you and I could be transported back to a thousand years ago, we would gaze upon a different world of living things.

To be sure, the same kinds of living things were present then that are present now. We would see human beings, horses, cows, pigs, fruits, vegetables, and grains. But we would observe great differences in the characteristics displayed by those living things of a thousand years ago and

those of today. Even the people would be different. So far as their form and structure were concerned, they would be like the people of today. But their behavior would be quite different. Their world lacked the refinements and advantages of our modern world, and their behavior was adapted to the relatively crude surroundings in which they lived.

If you could compare the vegetables, fruits, and grains of a thousand years ago with those of today, you would also find great differences. Our domesticated plants are very different from the wild ancestors from which they are de-

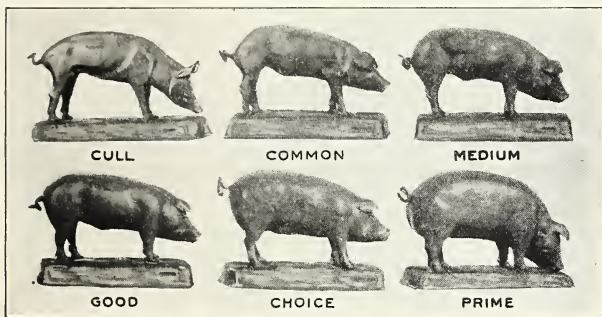


FIG. 297. Models of hogs, illustrating the various grades. Compare the cull (poorest grade) with the wild hogs in Figure 420. Note how similar they are.

scended. You may be familiar with wild grapes, crab apples, roses, gooseberries, rice, and other wild plants. You probably have tasted wild grapes, wild crab apples, and other fruits. Some of them are delicious; others are sour or bitter or full of seeds. All of them differ in size, taste, or in some other characteristics from the domesticated varieties.

During the thousands of years since man first began to domesticate living things, he has worked to produce plants and animals which would better meet his needs. That he has succeeded in this task is easily proved by comparing our domesticated varieties of plants and animals with their wild

ancestors. Domesticated fruits are larger and sweeter, domesticated horses are faster and can pull greater loads, domesticated sheep have better wool, and domesticated grains produce a greater yield than the wild varieties.

Improvement in living things has also been brought about by Nature herself. Millions of years before man appeared on the earth, living things were being selected by Nature on the basis of their fitness. Those which were adapted to meet



FIG. 298. How man improves corn. Plant 1 is a *pure-bred* variety called Lancaster Surecrop, shown for comparison. Plants 2 and 4 were cross-pollinated with each other, and from their seed grew Plant 3. Plants 4 and 6 were cross-pollinated, and from their seed grew Plant 5. Notice that Plants 3 and 5 are both taller than the parent plants 2, 4, and 6.

the various conditions of the environment survived; those which were not adapted perished. Even today these forces are operating to determine which species will survive. Man has in no wise changed or modified natural laws; he has only discovered and used them in producing the changes which he wishes. Man is able to produce changes in living things by following the methods practiced by Nature herself.

Man cannot create new living things. He cannot change them by himself. Living things have within them the possibility of change. Through hundreds and perhaps thousands

of years man was ignorant of how these changes were brought about in living things. The methods which he employed to secure better plants and animals were largely those of "trial and success." But, during the past hundred years, through experimentation he has discovered the laws which operate to produce changes in living things and has applied them to improve plants and animals for his own use.

Some of the questions which you should be able to answer when you have finished this unit are: How has man produced our domesticated apple from the wild crab apple? How can man grow ten different kinds of apples on the same tree? How can different fruits be crossed to obtain entirely new fruits? How are seedless oranges and grapes grown? How are plants developed which resist certain kinds of diseases? How can the yield of a certain plant be increased? How can man produce grains composed of just the right proportion of carbohydrates, fats, and proteins necessary for his use? All of these questions, and many others, can be answered if one understands how Nature operates to preserve the characteristics of living things and how, at the same time, she provides for the possibility of change.

### PROBLEM 1: WHY IS IT POSSIBLE TO MODIFY LIVING THINGS?

**STUDY SUGGESTION.** In Unit V you learned something about the struggle for existence and how the survival of a living thing depended upon its adaptation to the environment. You also learned that changes are constantly taking place in living things, resulting in new forms of life. In this problem you will learn how these changes in the structure of living things are brought about. It would be desirable to review Problem 5 and Problem 6 of Unit V, as you will probably understand them better, and they will help you in your study of this problem.

When a farmer purchases a bushel of seed corn and plants it, he expects, if conditions are favorable, to raise a crop of corn. He is absolutely certain that the seeds will develop

into corn plants, and not wheat or oat plants. And if the seed from the crop he has raised is planted, he will raise another generation of corn plants. These statements, of course, may appear rather foolish, but they illustrate one of the fundamental principles of biology, namely, that successive generations tend to resemble their parents. This tendency is known as *heredity*. This tendency makes it possible to predict within limits the characteristics of a forthcoming generation of plants or animals. It is through



FIG. 299. Note how the markings of this calf resemble those of the father at the left. If the mother had been of the same breed as the father, the markings would have been even more similar than they are here.

the application of this principle to plant and animal breeding that man has been able to produce changes in living things.

**Why do living things differ in some respects from their parents?** While living things may resemble their parents in many ways, they cannot be exactly like both parents. This would be possible only if the two parents were exactly alike. Observation of the characteristics of living things has shown that there are no two individuals exactly alike. Individuals differ in color of hair, texture of hair, shape of nose, hands, or other parts of the body, color of skin, length of various body parts, and many other characteristics. Of course, the two parents might have hair of the same color, in which case

the offspring would resemble both parents in this respect. But many of the characteristics would be different in the two parents. The offspring might possess certain characteristics of one parent and certain characteristics of the other parent. The result, therefore, would be offspring which would differ in some respects from both parents. Since both parents contribute to the offspring, there is thus secured the possibility of *variation*, that is, the possibility of a change in the form and structure of living things. If it were not for this,

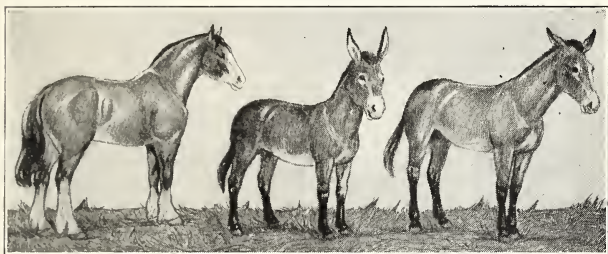


FIG. 300. The mule, shown at the right, is the offspring of a male donkey and a female horse. In size, strength, courage, smoothness of hair, and formation of teeth it resembles the horse. In certain physical characteristics and in patience, endurance, and sure-footedness it resembles the donkey.

man would find it difficult, if not impossible, to improve the living things which he selects for his use.

If you look about you, you will find abundant evidence to show that variations or changes take place. For example, if you picked at random one hundred ears of Golden-glow corn, you would find that the number of rows of kernels would vary from about eight to twenty-six. The average is usually about sixteen to eighteen rows, there being very few of the extreme conditions. Variation in the length of beans is shown by Table 15, on the next page.

If one selects a hundred or more plants or animals of a given species and examines them for given characteristics,

variations such as are shown in Table 15 will always be found. As we shall see in Problem 2, variation enables man to improve the living things which he selects for his use.

TABLE 15. VARIATION IN LENGTH OF BEANS FROM A CROSS BETWEEN A LONG-AND SHORT-SEEDED BEAN (Data from Johanssen)

| LENGTH IN MILLIMETRES | NUMBER OF SEEDS |
|-----------------------|-----------------|
| 9—10.....             | 2               |
| 10—11.....            | 20              |
| 11—12.....            | 136             |
| 12—13.....            | 540             |
| 13—14.....            | 1068            |
| 14—15.....            | 1125            |
| 15—16.....            | 636             |
| 16—17.....            | 180             |
| 17—18.....            | 18              |

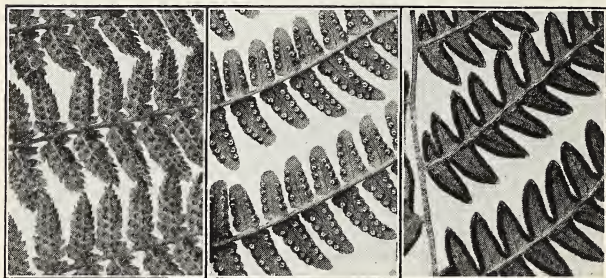


FIG. 301. The unit characters of these different kinds of ferns are plainly seen in the shapes of the leaves and the arrangement of the spore-bearing bodies. (L. W. Brownell photos.)

Observation and experimentation with living things have shown that individuals are made up of more or less independent characters, or what are generally called *unit characters*. For example, there are many varieties of peas, each of which has one or more distinguishing characteristics or unit characters. The ripe seeds may be deeply wrinkled or smooth; the seed coats may be brown or white or gray or green or yellow; or the unripe pods may be green or yellow. A given plant has many unit characters. For example,

it may have the following: tallness, a certain form of the seed, a certain color of the pod, etc. Each of these unit characters is handed down to the next generation as a unit.

#### SUGGESTED ACTIVITY.

Accurately measure and record the height of each pupil in the class. Record also the age. Make a graph for pupils of each age group, showing the number of pupils of each height. If the class is small, obtain records from other pupils in the school. What variation in height is shown? What is the average height for each age group?



FIG. 302. *Chromosomes in the cell of a Spider Lily (Tradescantia virginica).* (Photomicrograph by Dr. Paul Sedgwick.)

**How are characteristics transmitted from the parents to the offspring?** In Unit IV you learned how living things reproduce. You remember that during the process of fertilization the sperm cell unites with the egg cell. The fertilized egg, by a process of cell multiplication (Unit III), finally develops into an adult plant or animal. Since the new individual grows from a fertilized egg, it is evident that the sperm cell and the egg cell must contain all of the unit characters which determine the kind of individual that is to be produced. Not only is this true, but certain unit characters, often different in kind, are present in both the parents. For example, one plant may bear yellow and the other green seeds, or one plant may be tall and the other short. The offspring manifestly cannot be both tall and short. To understand what determines the characters which the offspring will have, we must study the process of fertilization.

If the nucleus of a plant or animal cell which is dividing is examined under a high-power microscope, it will be found to contain rod-like structures or other bodies (Figure 302).

These are called the *chromosomes*. The number of chromosomes varies with the different species of animals and plants. These chromosomes are thought to be bearers of the hereditary characters. It used to be believed that each unit character was represented in the chromosomes by a certain factor, or *gene*. It is now believed, however, that there are many genes which coöperate in producing a unit character. There

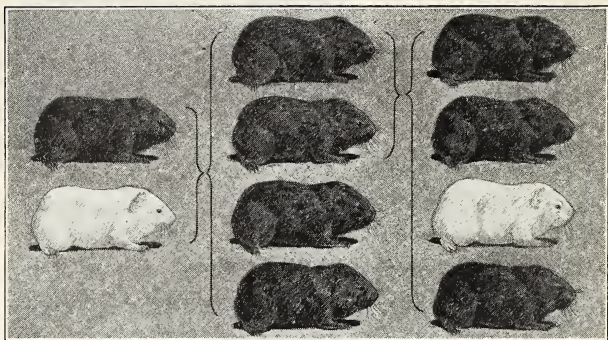


FIG. 303. Color inheritance in guinea pigs. Although the first generation are all black, yet they have both black and white genes, as shown by the fact that one of the offspring of two of these black, first-generation guinea pigs is white.

are thus thousands of genes in the chromosomes, which act together to produce the character of the living thing as a whole. All of the bearers of unit characters of a parent are present in the sperm cell of the male or the egg cell of the female. When the sperm cell and the egg cell unite, the fertilized egg will thus contain two sets of genes, one set having been inherited from each parent.

When two sets of different genes are brought together, what happens? Suppose that a black guinea pig mates with a white guinea pig, what is the color of the offspring? It might be thought that the colors would blend to produce a

gray or a black-and-white guinea pig, but such is not the case. The offspring of the first generation are black. The gene for black is stronger than the gene for white. The character which prevails when two different sets of genes are brought together is called the *dominant character*, and the one which is suppressed is called the *recessive character*. It must not be concluded that because a given unit character does not appear in a given generation, the character is lost. The offspring of the black and the white guinea pigs still possess both genes. If these offspring are mated, the next generation will be three-fourths black and one-fourth white. The white character may thus appear in succeeding generations. This is true because the genes do not blend. Each retains its independence or unity.

Through the work of Gregor Mendel, an Austrian monk, it is possible to predict mathematically the nature of the offspring when the characters will not blend. Mendel chose two strains of peas, one with yellow seeds and the other with green seeds. He cross-pollinated the two strains of plants (Unit IV). This was accomplished by removing the stamens from flowers of some of the plants and dusting the pollen from one strain upon the stigma of the other strain. The flowers were then covered with paper bags to prevent any more cross-pollination taking place. The fertilized egg thus contained



FIG. 304. Gregor Mendel (1822-1884), through whose patient, careful work man has learned how the characteristics of living things are passed on from parent to offspring.

bearers of both of these unit characters. When the seeds were mature, he planted them; and the result was a generation of peas with yellow seeds. The yellow was thus dominant over the green. He cross-pollinated the plants of this generation and grew the seeds produced; the result was a mixture of plants, some of which bore green seeds and some of which bore yellow seeds. There were, however, three plants bearing yellow seeds to every one bearing green seeds.

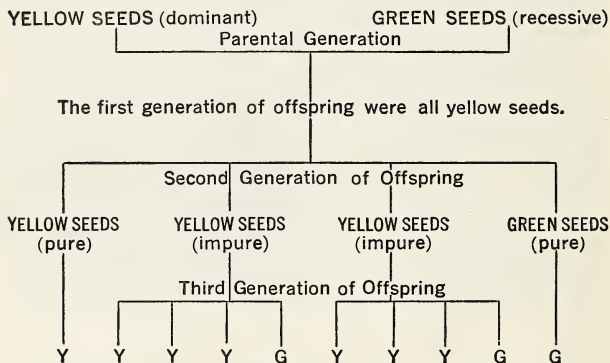


FIG. 305. Diagram of color inheritance in pea seeds, as demonstrated by Mendel's experiments.

When the plants with green seeds were cross-pollinated with pollen from other plants bearing green seeds, they produced nothing but plants with green seeds. The plants with the yellow seeds, however, behaved differently. Some produced descendants with pure yellow seeds, and some produced another generation, part of which bore green seeds and part of which bore yellow seeds. The same proportion again appeared, namely, three plants with yellow seeds to one with green seeds. The plants which contained both the yellow and the green seed characters and which produced a mixed generation have been called *hybrids*. Hybrids, if cross-

pollinated, produce a generation in which one-fourth of the plants will show one of the characters and will *breed true*, one-fourth of the plants will show the other character and will breed true, and one half of the plants will be hybrids like the parents and will produce a mixed generation (Figure 305). This mathematical statement of the way in which two different genes behave when they are brought together is known as Mendel's law.

In the examples cited above, one set of genes was stronger than the other, that is, it was completely dominant over the other set. As a result, the hybrids took the color of the dominant set of genes. In some cases, however, one set of genes is not completely dominant over the other, and the offspring may present a characteristic intermediate between the two. For example, if a red Four-o'clock is crossed with a white Four-o'clock, the flowers of the first generation will be pink. When these flowers are cross-pollinated, one-fourth of the offspring will be red, one-half will be pink, and one-fourth will be white. It is not possible to obtain pink Four-o'clocks which will produce all pink flowers. As a rule, however, one set of genes is completely dominant to the other.

The experiments of Mendel and others show how variations occur. The offspring vary from their parents because they receive different mixtures of genes from each parent. Some of these genes are dominant over others, and the result is an individual having unit characters which are different from those of each parent. The variations which occur as the result of this mixed inheritance of genes make it possible for man to select the unit characters which he wishes and to produce plants and animals bearing these characters. How this is accomplished will be considered in Problem 2.

**SUGGESTED ACTIVITY.** Study the pupils in your class and prepare a list of the specific characteristics that distinguish them from each other.

**SUGGESTED ACTIVITY.** Collect leaves from some species of plants. Can you find any two leaves which are exactly alike?

**Why are living things constantly changing?** Occasionally, living things appear possessing characteristics which cannot be explained by the already existing characters of the race. For example, there appeared in Colorado in 1910 a sunflower with red flowers. Seeds from this plant were grown, and the succeeding generation also developed red flowers. In other words, it bred true. It could not have been a hybrid, because in this case the succeeding generation would have followed Mendel's law. It was evident therefore that

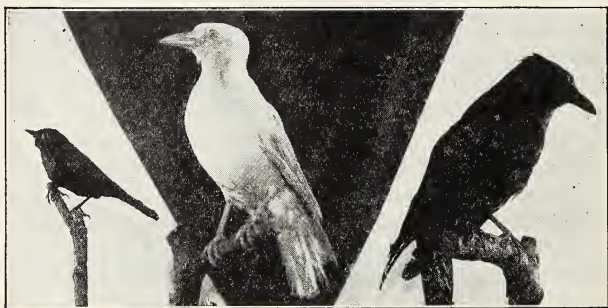


FIG. 306. Occasionally there appears as a *mutant* an animal that is pure white, while others of its kind are black, or some other solid color. Such mutants are known as *albinos*. This picture shows an albino crow. At the left is a relative of the crow, a blackbird.

this was a new species of sunflower. Changes of this kind have been called *mutations*. Scientists have not definitely determined the exact cause of mutation, but it is thought to be caused by some change in the genes or some change which affects the chromosomes. Mutations may give rise to new species and probably account in part for the many species of plants and animals. If the new species formed by mutation presents some character which adapts it better to the environment than the original species, it tends to survive and may even eliminate the old species by natural selection. Living things have within themselves the possibility of continuous

improvement from generation to generation. Mutations which appear are often selected and cultivated by man, resulting in living things that are better adapted to his purpose.

The possibilities of change in living things which have been considered up to this point have been concerned with changes brought about through the action of the genes. These changes, of course, may be inherited by the next generation, and so through generation after generation there is constant variation. The variations which result in living

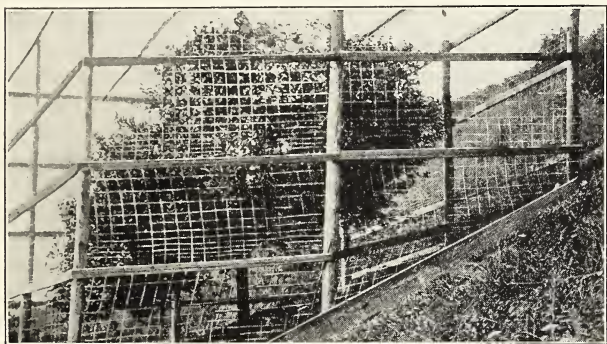


FIG. 307. Some years ago there was discovered on a West Virginia hillside an apple tree bearing a golden-colored apple that had the shape and the flavor of the well-known dark red Delicious apple. This was a mutant. Now we have the Golden Delicious apple. (Photo from Stark Brothers Nurseries.)

things well adapted to the environment survive and are passed on to succeeding generations. Disadvantageous variations usually result in the early death of the individual and thus are not transmitted.

Another possibility of producing changes in living things is brought about by the action of environmental factors upon living things. By this we mean the total physical surroundings, such as the varying conditions of moisture, temperature, food, and light. The ways in which living things adjust

or fit themselves to the environment have been discussed in Unit V. One of the earlier theories, that of Lamarck (1744-1829), a French zoölogist, attempted to account for the constant variation of living things and the development of new species on the basis that modifications which occur in living things as a result of their reaction to the environment can be transmitted to the offspring. Much experimentation has been carried on to determine if this is true. At the present time there is no evidence to justify a belief in or to establish the truth of this theory. The feet of women in China, for example, have been bound for thousands of years. According to this theory it would seem that there should be a gradual decrease in the size of the feet of Chinese women. No such decrease, however, occurs. It would also appear by this theory that a child of a great musician born after the parent has acquired skill would possess more musical skill than a child of the same musician born before he has acquired skill. This, however, is not true. In the present state of our knowledge there is not sufficient evidence to justify the belief that modifications acquired during life can be inherited.

The environment, however, does play a part in modifying living things, because only those living things which are adapted to live in it may survive. From the viewpoint of man, the environment is an important factor in modifying living things which he selects. Through the regulation of conditions and materials he can modify the living things of any one generation. Although these changes are not inheritable, he can produce another generation with the same characteristics by again regulating conditions and materials.

**SUGGESTED ACTIVITY.** Write to companies which sell seeds or nursery products and obtain one of their catalogues. Make a list of the new kinds of plants shown.

**Self-testing exercise 1.** Write a paragraph in which you explain (1) why it is possible for variations to occur, (2) how variation takes place, and (3) how variation helps us to understand the great variety of living forms which we now have.

## PROBLEM 2: HOW DOES MAN IMPROVE LIVING THINGS BY SELECTION AND BREEDING?

**STUDY SUGGESTION.** Problem 1 presented the general principles underlying the improvement of living things. In this problem the practical application of these principles by the farmer, the animal breeder, and the horticulturist will be discussed. Your study should result in an understanding of the methods employed in improving plants and animals and also of the value of the methods from an economic standpoint.

In Canada man's skill in adapting living things to his needs has solved at least one outstanding economic problem with outstanding success—that of discovering, or more exactly, creating, a quality spring wheat which yields well and still ripens soon enough to escape the prevailing early frosts in our Canadian West.

The Red Fife commonly grown on the prairies at the end of the last century met these specifications except that it matured dangerously late in the season. The search for a perfect spring wheat became the special charge of the Dominion Experimental Farms System inaugurated in 1886.

The first move was to make a trial in Canada of wheats grown successfully in other countries under conditions similar to Canada's. Seventy-four varieties were imported for plot trial in 1889, most of them from northern Russia and the higher plateaus of India. Ladoga, native to the region north of Leningrad, was found to ripen early, to yield well, and in preliminary tests to bake well. Three-pound bags of seed grain were accordingly sent to several hundred western farmers. Further trial showed that while the field qualities of good yield and early maturity remained stable, Ladoga lacked the strength of gluten which the millers of the world had come to expect and demand of Canadian wheat.

Meanwhile, in the event of no wheat plant being found to meet the standards set, the Director of the Experimental Farms, Dr. William Saunders, and his assistants were using their skill to create a plant of the type desired by *crossing*.

Heredity, you learned in Problem 1, ensures the reappearance in the offspring of the stable or permanent characteristics of the parents. This means not only that identical parents will produce identical offspring, but also that dissimilar parents will produce offspring dissimilar to either parent and showing the different parental traits in some new combination. Dr. Saunders had scientific reason to believe then that if two varieties of wheat could be found which between them made up the sum of the qualities desired, a cross-breeding of the two strains should produce sooner or later the perfect spring wheat.

This much for the principle. The method has been previewed for you in Unit IV. Cross-breeding or cross-pollination means the artificial transference of the fertilizing element—the yellow dust or pollen—from the anthers of one variety to the stigmas of another. Self-pollination in the latter has been prevented by removal of its anthers before they have emitted their pollen. The newly-introduced pollen grains develop a small tube which penetrates downward to the embryo sac. There the pollen tube discharges the sperm cells, which unite with the egg cells to form a mass containing the characters of the two parent plants.

The initial efforts of Dr. Saunders and his staff produced worth-while, if not startling, results. Out of crosses between Ladoga and Red Fife came such varieties as Preston, Stanley, Huron, and Percy, wheats maturing earlier than Red Fife but of inferior quality. In 1892 Dr. Saunders discarded Ladoga and brought together for the first time the high-quality, prolific Red Fife and the early-maturing Hard Red Calcutta, ultimately to produce the superb Marquis wheat.

The advent of Marquis wheat into Canadian agriculture can accurately be called epoch-making. Within twelve years of its introduction, Marquis occupied not less than 90 per cent of all the spring wheat area in the Dominion. Its popularity was due to its ability to ripen from three to ten days earlier than Red Fife, to its greater strength of straw, and to its greater yielding ability and high baking quality.

Observe the two principles of plant improvement involved in this work. In 1892 no one could foresee that any such banner wheat as Marquis would emerge from



FIG. 308. A fine stand of Marquis wheat.

the crossing of Red Fife and Hard Red Calcutta. For it was not merely a question of crossing two varieties and from the seed obtained producing at once the variety we call Marquis. Between that cause and this effect necessarily intervened years of painstaking work. The reason is that when two plants are crossed, the bad qualities as well as the good are transmitted to the offspring. Both patience and discernment are needed to choose from among the derivative plants that which contains good characteristics in the highest degree and bad characteristics in the lowest. In fact, the Cereals Division of the Experimental Farms System—under the direction now of Dr. Charles Saunders, a son of Dr. William Saunders—was not ready to release Marquis

for trial in the Prairie Provinces until 1907. Between 1892 and 1907, Charles Saunders took his father's original Red Fife-Hard Red Calcutta hybrids several times through the process of cross-pollination—from a variety of strains selecting and fostering always the most desirable and improving even on it by further cross-breeding. His procedure, in effect, was by cross-breeding to encourage nature to produce new variations, and to *select artificially* from the variations offered those containing in highest degree the qualities desirable to man.

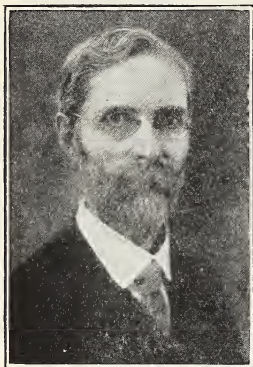


FIG. 309. The late Dr. William Saunders, producer of Marquis wheat. Dr. Saunders was knighted for his contribution to Canadian agriculture.

Evidently we have here, supplementing each other, two principles which man may employ in altering living things to his taste—selection and cross-breeding. Generally as in the development of Marquis wheat, the two go together. Cross-pollination results in the creation of undesirable as well as desirable varieties, and so always involves rigorous examination

and selection of the new strains. But artificial selection alone is sometimes effective in improving living things, as you will now see.

**What methods are employed to select and propagate desirable characters?** The corn grown in such large quantities in the central United States is used by farmers to feed stock and by industry in the making of different products. Industry demands a corn which is high in oil content. The stock men, on the other hand, desire a corn with low oil content, because corn with a high oil content produces an animal with soft, flabby flesh. In 1896, the Illinois Agricultural Experiment Station set itself to produce

the two corns desired. From among varieties of corn grown successfully for a number of years, samples were chosen showing both high and low oil content. The yield from these samples was carefully scrutinized for the two plants highest and lowest in oil content respectively. These in turn were planted, and their progeny examined for the qualities desired. This was continued for ten years until two strains of corn widely separated in oil content were developed.



FIG. 310. Rambouillet sheep, a breed native to France, but now very common in our country, particularly on the Western ranges.

The experiment described in the paragraph above showed clearly that plants can be changed and improved by artificial selection. Is it possible to use the same method in changing the characters of animals? Observation of animals shows that they vary in much the same way as plants. For example, the fleeces of 100 Rambouillet ewes of the United States Experiment Station, Dubois, Idaho, were studied. The ewes were divided into four classes on the basis of their fleece length, averaging 1.3 inches, 1.8 inches, 2.3 inches, and 2.8 inches, respectively. The fleece length of each class was compared for three years. The results showed that, class for class, those ewes producing the shortest fleece the first year continued to produce the shortest fleece the succeeding years, and similarly for the other classes. Length of fleece is thus a character in which sheep vary. Selection

for breeding purposes of the ewes with the longest fleece would therefore result in a flock of ewes in which this character would be dominant. It is evident, however, that the improvement of animals is a much slower process than the improvement of plants. In a given generation only a few animals are born, while plants may produce hundreds of seeds. There are, therefore, a greater number of variations from which to select in plants than there are in animals.

Mass selection in animals, as with plants, is not as effective in producing animals with uniformly high qualities as other methods which can be practiced. For example, an experiment with chickens was carried on at the Maine Agricultural Experiment Station. Hens were selected which had laid 160 eggs or more their pullet (first) year. These hens were mated with males whose mothers had laid 200 eggs or better. The selected birds were mated at random, and the selection was carried on for five years. No increase in the average yield was obtained. The method of selection was then radically changed. The hens were chosen not only upon the basis of their egg yield but also upon the basis of the egg yield of their daughters. Similarly the males were chosen on the basis of the egg yield of their daughters. The result was a greatly increased egg yield. This method of selection is known as the *progeny performance* method. The parents, by this method, are chosen not only for their own high performance but also by their ability to transmit this character to their offspring. This method has been successfully applied to horses, cows, swine, and sheep, and is far superior to the "mass" selection method.

**SUGGESTED ACTIVITY.** Make a study of your brother or sister. In what ways do you resemble them? In what ways do you differ from them? In what ways do you resemble or differ from your father? Your mother?

**SUGGESTED ACTIVITY.** Compare a young cat or dog with its father and mother. Make a list of the characteristics in which it resembles (a) its mother, (b) its father, and (c) neither parent.

**How are desirable characters propagated by regeneration of missing parts?** The methods of improving plants and animals, so far described, are based upon the selection of parents with good qualities, and the further selection of the best offspring of each generation. The methods of improving most of the fruits and berries are quite different from those employed to improve grains and live stock. Plants such as wheat, corn, oats, beans, peas, and radishes come to maturity and produce seeds the first year of their growth. Fruit trees, on the other hand, do not bear until they are several years old. Fruit trees are like other plants in that their offspring vary greatly. If grown from seed, several years would thus elapse before the worth of the tree could be determined. Raising fruit trees is expensive both in labor and in the amount of land occupied; hence the method of securing desirable trees through the selection of the seed of good-bearing trees is impracticable.

Fortunately, however, there is a method by which a tree with desirable characters may be perpetuated. You recall (Unit IV) that certain plants may be propagated by vegetative reproduction. Cuttings, bulbs, and buds taken from a plant will, if the necessary conditions are present, regenerate the missing parts and thus grow into a new plant. Since no transmission of characters through bi-parental reproduction is involved, the new plant which grows will have characters which are identical with the plant from which the cutting, bulb, or bud is taken.

Grapes, currants, gooseberries, willows, geraniums, and many other plants are commonly propagated by means of cuttings. Plants are selected which bear fruit with desirable qualities. Cuttings may be made from roots, stems, or even from leaves. Stem cuttings are usually obtained from younger growths which have one or more buds. One end of the cutting is placed in sand, soil, or water, and if the correct temperature is supplied, roots will develop, and the buds of the cutting will develop new branches, leaves, and

fruit. Sometimes the cuttings are made in the autumn and stored in damp sawdust throughout the winter. Short cuttings from roots of hardy plants like the red raspberry, plum, and blackberry are often made. When these are planted and supplied with the correct amount of moisture and heat, they develop a stem and grow into a plant with the same characteristics as the parent plant. Sometimes a live branch of a tree is bent down and covered with earth for



FIG. 311. Steps in cleft grafting. At the left are the scions inserted in the cleft of the stock. Wax is then applied to protect the tree from injury and disease. At the right are shown the scions well along in growth. (International Harvester photos.)

part of its length. The part buried develops roots and sends up a new stem which will grow into a new tree. This method is known as *layering* and is often practiced with apples, pears, and plums. The horticulturist thus takes advantage of the ability of plants to replace or regenerate lost parts.

**How are desirable characters secured through grafting?** Fruit trees may also be propagated by *grafting*. In grafting, a piece of stem with its buds is taken from one plant and inserted into the stem of another plant (Figure 311). The stem is inserted in the other stem in such a way that the cambium layers (page 124) are in contact. The growth of

the cambium layers results in the two stems growing together. The shoot which is grafted is called the *scion*, and the plant upon which the scion is grafted is called the *stock*. The buds which develop on the scion always produce fruit which have the characteristics of the scion.

For example, if a scion of the Ben Davis apple is grafted on a Jonathan tree, the fruit which develops on the scion will be of the Ben Davis variety. The tree may, therefore, bear both Jonathan and Ben Davis apples at the same time. The scion retains the characters of the plant from which it was cut and develops fruit like that of the parent plant.

Wild varieties of plants often develop root systems which are better adapted to the environment than those of the domesticated variety.

Wild oranges, for example, develop strong, hardy roots which enable the plant to grow in a colder climate than our domesticated sweet varieties. For this reason, seedlings of the wild orange are often grown, and a scion from the domesticated variety is grafted upon them. American grape growers imported to this country some of the wine grapes of France. The roots of this imported grape were attacked by a small insect known as *Phylloxera* and were practically destroyed. The roots of American grapes, however, could resist the attack of this insect. The European grape was accordingly grafted on the American plant, and this variety of grape was successfully introduced into this country. In this way the character of a plant resistant to disease is combined with the character of a plant bearing desirable fruit.

Sometimes the buds from a plant with desirable qualities are detached from the parent plant and inserted under the bark of another plant which has less desirable qualities.

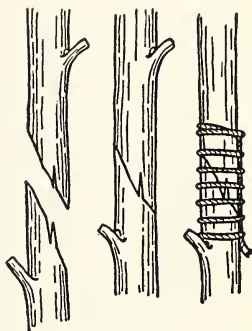


FIG. 312. Tongue or whip grafting

The buds produce new branches, and the fruit which they bear is like that of the plant from which the bud is taken. Desirable varieties of peaches and cherries are often propagated in this manner. In order to economize on space, one tree



FIG. 313. Stages in bud grafting.

may be used as a stock for scions taken from several hundred different varieties. Those scions which develop desirable fruits are then propagated the following year through budding or grafting.

Artificial selection of plants and animals has thus resulted in a great improvement of the living things which man has domesticated. Through variations and mutations desirable qualities appear in plants and animals. These qualities are often inherited by the next generation. Through the selection of desirable variations man can thus improve his stocks of plants and animals. If propagated through sexual reproduction, not all of the next generation will be high in the desired qualities. The average, however, will be higher than if the parents had not been selected.

Continuous selection of the best of each generation, when practiced over a period of years, will result in the production of better plants and animals. In the case of perennial plants selection may also take place by choosing the best of each generation. In practice, however, it has been found advantageous to propagate the desirable characters through vegetative reproduction. Some variation may occur by this method, but in general the new plants grown will possess the same characters as the parent plant. Here again, however, artificial selection is practiced in choosing the types of characters to propagate.

In selecting the plants and animals which he wishes to propagate, man is only practicing on a small scale what Nature practices on a large scale. Every living thing that comes into existence must meet the demands of Nature. Nature demands that they fit the environment, or adjust themselves to it. If the living thing does not fit the environment, and if it cannot adjust itself to the conditions of the environment, it perishes. As a rule it perishes before it comes to maturity, and thus only those living things which are adapted to the environment become the parents of the next generation. The vast number of the progeny of living things results in a struggle for existence (Unit V). Only the strong survive, and thus by a process of natural selection the best adapted living things are chosen to pass on their characters to the coming generation. The selection of the fit by Nature is of course a slow process. Man hastens this process by artificially selecting the living things with desirable characters and allowing only these to reproduce.

In returning now to the study of cross-breeding, observe again that the breeder must use artificial selection to perpetuate his new species, and that the two methods interlock.

**How are new varieties of plants produced?** Have you ever eaten a white blackberry? You may think that such a plant does not exist, but there actually is a plant of this kind. Blackberry is, of course, the name of a species of plant which probably received its name from the color of the berry. How man was able to produce a blackberry so transparent that the seeds may plainly be seen illustrates further how plants with new qualities can be created by the method of cross-breeding discussed earlier in the problem.

The creator of the white blackberry was Luther Burbank of California. Burbank was a pioneer in the field of practical plant breeding, and probably contributed more toward the improvement of plants and toward the creation of new plants than any other individual. Burbank heard of a wild blackberry which bore small berries of a muddy-brown color,

and he conceived the idea of producing a white blackberry. He obtained some of these berries and crossed them with the Lawton blackberry (some pollen from the Lawton was sprinkled on the stigma of the wild blackberry). The Lawton blackberry bore large black berries of good quality and was an exceedingly stable variety. The seeds which developed in the berries of the cross-pollinated wild plants were planted and grown. The seeds which developed from these plants



FIG. 314. Starting over fifty years ago with twelve seedling trees imported from Japan, Luther Burbank finally developed the blood-red Elephant Heart plum, in size almost as large as an apple. Notice how much larger it is than the common Green Gage plum shown at the left. (Photo from Stark Brothers Nurseries.)

grew into plants which bore black berries. This result, of course, was expected, since the black character is dominant over the white character. These hybrids were then interbred, and the resulting seeds were planted. In this generation there appeared several plants which bore black berries and several which bore yellowish-white berries. According to Mendel's law, this result was also to be expected.

Since Burbank's aim was to produce a white blackberry, he selected and cross-pollinated plants which bore the yellowish-white berries. In the next generation several plants

appeared with berries so white and transparent that the seeds could be plainly seen. The best of these were selected and grown, and by carrying on this process of selection for several generations, the white blackberry was created. This berry possessed the fine flavor and size of the Lawton blackberry combined with the whiteness of the wild blackberry. That it is a new, distinct species or variety is shown by the fact that it breeds true to the seed. If it were merely a hybrid, there would appear the variations that are common to all hybrids.

In a sense, Burbank did not create an absolutely new plant. He combined in a new way characteristics which were already present in both plants. The wild blackberry which bore the muddy-brown berries was probably a mutant which had appeared and survived the process of natural selection. By continued selection of berries possessing the character of whiteness, Burbank was able to produce plants which did not bear the character of blackness, and thus would breed true. When a plant or animal breeder desires to produce a living thing with certain characteristics, he first looks for varieties bearing these characters. One variety may have one or two desirable characters and several undesirable ones. For example, the wild blackberry had but one desirable character, whiteness, and several undesirable characters, such as small size and poor quality. Another variety may possess the desirable characters which the other does not have, and also one or more undesirable qualities. By cross-breeding these desirable characters are brought together in a single plant. For example, the Lawton berry had a large, luscious fruit, which was a desirable character, and a black berry, which, in this experiment, was an undesirable character.

The breeding process may take many years and require the raising of millions of plants. Only a few of the best plants of each generation are saved, and the remaining thousands are destroyed. Burbank, for example, in his experiments with blackberries burned 65,000 blackberry bushes in one year.

Ultimately, through careful selection of the plants bearing desirable characters, a plant emerges with the characters which the breeder wants. Sometimes this plant is propagated by grafts or cuttings, and sometimes, if the seed will breed



FIG. 315. Luther Burbank planting one of his new variety of walnut tree. (Wide World photo.)

true, it may be propagated through seeds. In either case this plant becomes the parent for a new variety which may ultimately spread over countless acres.

Occasionally cross-breeding produces strange and unexpected results. This happened when Burbank crossed the California black walnut tree with the Persian, or English, walnut. When the hybrid nuts were planted, they produced seedlings which grew exceedingly fast. At sixteen years of age they were sixty feet in height with a trunk two feet in diameter four feet from the ground, while the Persian walnuts of thirty-two years of age were but eight inches in diameter with a branch spread

of but one-fourth that of the hybrid. Seeds from the hybrid were planted, and through selection a species of walnut was secured that produced a hard, close-grained wood of great value for fine furniture. The distinguishing characteristic of this new tree was its exceedingly rapid growth; it produced wood for the cabinetmaker in from six to eight years.

Burbank and other breeders have produced many new varieties of plants by crossing plants in every conceivable way. The plants resulting from the crosses are carefully examined, and if any possess unusual characters, they are

propagated. This method differs from the method of carefully selecting the characters which it is desirable to produce in that the breeder is trusting to variation to produce a plant which may be of value. While this method is not as scientific as the other method, many new varieties have been thus produced.

Experiments in *hybridizing*, that is, crossing plants or animals of different varieties, have shown that hybridizing often results in offspring with increased vigor. Animal breeders have taken advantage of this fact from early times. When the Chinese races of swine were introduced several hundred years ago into England, they were commonly crossed with the native swine

because they produced large, quick-growing animals. Experimentation with plants has shown that the same results may be obtained. Table 16, on the next page, shows the results of crossing varieties of sweet corn. There is an increased yield in practically all of the crosses made. Hybridizing corn is comparatively easy because the corn has two kinds of flowers. The two varieties to be crossed are planted in alternate rows. The tassels of one variety are removed, and the female flowers (the silks) on this plant can thus be pollinated only by pollen from the other variety.

There are many theories concerning the cause of hybrid vigor. In general it is believed that the cross is advantageous because the deficiencies of one plant are compensated for by



FIG. 316. A row of Dwarf Yellow Milo corn (behind the stake) ruined by chinch bugs. At the left is a row of hybrid plants (Dwarf Yellow Milo crossed with Kansas Orange Sorgo) that has been little affected by the chinch bug. Crossing the two varieties produced a plant largely resistant to the bug.

the good characters of another plant. The offspring tend to bring together the favorable characters of both plants and surpass their parents. The effect, however, lasts only for the first generation following the cross; therefore continued crossing must be done unless the plant can be propagated by means of vegetative reproduction.

TABLE 16. YIELD PER PLANT OF TEN SWEET-CORN HYBRIDS COMPARED WITH THAT OF THEIR PARENTS\*

| HYBRIDS                        | AVERAGE<br>YIELD OF<br>PARENTS<br>(OUNCES) | YIELD<br>OF<br>HYBRID<br>(OUNCES) | PER CENT OF<br>INCREASE OF<br>HYBRID OVER<br>AVERAGE OF<br>PARENT |
|--------------------------------|--|-----------------------------------|---|
| Early Minnesota by Sugar . . . | 1.15                                       | 1.50                              | 30.0  |
| Sugar by Early Minnesota . . . | 1.15                                       | 2.02                              | 75.0  |
| Sugar by Malakhoff . . . . .   | 1.22                                       | 1.54                              | 26.0  |
| Sugar by Crosby . . . . .      | 1.06                                       | 1.04                              | -1.9  |
| Crosby by Malakhoff . . . . .  | 1.03                                       | .76                               | -2.6  |
| Early Minnesota by Malakhoff   | 1.12                                       | 1.20                              | 25.0  |
| Mammoth by Malakhoff . . . .   | .79  | .99                               | 25.0  |
| Mammoth by Sugar . . . . .     | .77  | 3.10                              | 310.0   |
| Mammoth by Oakview . . . . .   | .16  | .45                               | 181.0   |
| Sugar by Oakview . . . . .     | .64  | 1.70                              | 165.0   |

**How is the breeding of animals improved?** Selection of the best animals for breeding purposes has, of course, been carried on for centuries. In different countries and in different sections of each country, different standards of selection were practiced. This variation in standards combined with variations in food and climate led to the development of distinct breeds of animals. For example, there was developed in Durham, England, a strain of cattle known as Shorthorns. Over one hundred years ago the development of this breed was begun by Charles and Robert Colling. So well does it thrive under different conditions of climate and food, that it is now found in more parts of the world than any other breed. From the beef Shorthorn has been developed a dairy Shorthorn for milk.

In another part of England a strain known as the Herefords developed, descended, it is thought, from the primitive cattle of the region. Henry Clay of Kentucky introduced this breed into America, and it has become popular on our Western plains because its rugged constitution and thick hair enable it to endure exposure to severe weather. Each strain was kept pure by breeding, and each strain has therefore developed along different lines so that it has certain definite characteristics.

About the middle of the eighteenth century the *pedigree* registration system began in England, and this marked the



FIG. 317. A group of splendid pure-bred Herefords. Perhaps you have seen some of this breed with their reddish-brown and white markings.

beginning of scientific animal breeding. Under this system each animal's name is recorded, a number is assigned, and the name and number of the *sire* (father) and of the *dam* (mother) are recorded. The pedigree thus indicates the family to which the animal belongs and is a guarantee of purity of blood. These animals are called *pure-breds*. The value of the pedigree lies in the fact that the ancestry of an animal can be traced and that the ability to transmit good characters to its offspring can be determined (see page 378). Since only the best animals of each generation are selected for breeding purposes, pure-bred animals are superior to animals where no attention has been paid to breeding.

Several different systems of breeding are followed: In *mixed-breeding* no attention is paid to ancestry. It is the cheapest method of breeding, but of course it does not result in improvement. In *pure-breeding* only registered animals are used. This system secures the best results, but since pure-bred animals are costly, this method of breeding is



FIG. 318. Result of grading in sheep. Note the poor wool growth on the mother (at the left). Her offspring by a pure-bred father is greatly improved as a wool producer.

expensive. The system most commonly practiced is called *grading*, in which the sire is pure-bred while the dam is not. This is less costly than the pure-bred method, and its results are nearly as effective. The fourth method is cross-breeding. In this system two different breeds are crossed. the object is to produce a new breed of animals. This is a long, expensive task and is practiced only by experienced breeders with plenty of money and time.

The effect of grading upon the productivity of chickens is shown in Table 17. The experiment started with a mixed

TABLE 17. FIRST-YEAR EGG PRODUCTION OF MONGRELS AND FIRST, SECOND, AND THIRD GENERATION GRADES

| BREED              | MONGRELS | FIRST<br>GENERATION<br>GRADES | SECOND<br>GENERATION<br>GRADES | THIRD<br>GENERATION<br>GRADES |
|--------------------|----------|-------------------------------|--------------------------------|-------------------------------|
| White Leghorn..... | 75       | 166                           | 197                            | 198                           |
| Plymouth Rock..... | 105      | 135                           | 166                            | 207                           |

lot of *mongrel* farm hens. (Mongrel means of mixed breed.) Pure-bred cockerels were used for breeding purposes, and in the third generation of hens the egg production was doubled.

**Self-testing exercise 3.** Assume that you are an agricultural expert from one of the Dominion Experimental Farms and that a farmer asks you this question, "How shall I go about improving my plants and animals?" What would be your answer to this question? (Keep in mind that the farmer may never have heard of Mendel's law and may know but little about heredity and variation. If you use these terms, you must explain them so that he will understand what you tell him. It is a good idea to strengthen your argument by showing how the improvement will result in a greater money reward.)

#### ADDITIONAL EXERCISES

1. Find out the contributions made by Darwin, Davenport, De Vries, Galton, Lamarck, Mendel, and Weismann to the science of heredity.

2. Why must the cambium layer of the stock come in close contact with the cambium layer of the scion in a graft?

3. What advice would you give a farmer about the selection of seed for the next year's crop?

4. Examine wild or domesticated animals. Make a list of the characteristics which are inherited.

5. Make charts similar to that shown on page 368 to show what will happen when the following crosses are made: (1) pure black and pure white guinea pigs; (2) pure black and hybrid black guinea pigs; (3) pure white and hybrid black guinea pigs; and (4) two pure white guinea pigs.

6. Find out how the grapefruit and the seedless orange were developed.

7. Make a report on the origin of each of five pure breeds of some domesticated animal. Your report should include a discussion of the particular characteristics, both physical and otherwise, which distinguish each breed.

8. Prepare a report on either corn or wheat. Your report

should include the origin of the plant, the development of the different pure strains, and the characteristics of each strain.

**9.** Collect pictures for a bulletin-board exhibit of different breeds of cattle. Do the same for sheep, hogs, and chickens.

## GLOSSARY AND PRONUNCIATION LIST

This is a list of the important scientific words in the text, together with their pronunciations and meanings. The marked letters are sounded according to the letters in the following list of sample words as given in Webster's Dictionary.

|   |                                       |
|---|---------------------------------------|
| āle, senāte, cāre, ām, ārm,<br>pāth, fīnāl, sofā. | ōld, ōbey, ôrb, ōdd, cōrn,<br>cōnnect |
| ēve, ēvent, ěnd, makē, re-<br>cĕnt.               | out, oil, nature, verdure.            |
| fōod, fōot.                                       | ūse, ūnite, ūrn, ūp, menū,<br>circŭs. |
| īce, īll.   | zh = z as in azure.                   |

ABDOMEN (ăb dō'mĕn): the part of the body below the ribs, containing the intestines; the posterior region of the body in insects, crayfish, etc.

ABOMASUM (ăb ō mā'sŭm): the part of the stomach of animals such as the sheep and cow in which the food is acted upon by the gastric juice; often called the fourth stomach.

ABSORPTION (ăb sôrp'shŭn): the passage of liquids into the cells of the body.

ACRIDIDÆ (ă krīd'ī dē): a family of the orthoptera which includes locusts and grasshoppers.

ACTIVE IMMUNITY (ī mŭ'nī tī): freedom from susceptibility to a specific disease resulting from a previous attack of the disease.

ADENOID (ăd'ĕ noid): a mass of tissue in the back of the pharynx; frequently this tissue becomes infected and must be removed.

ADJUSTOR (ă jŭst'ēr): that part of the nervous circuit which distributes nerve impulses.

ADVENTITIOUS (ăd vĕn tish'ŭs): the term usually applied to buds and roots which do not grow in their usual places.

ALBINO (ăl bī'nō): an organism lacking the pigments which give color; animals usually with white hair, fur, or feathers, and pink eyes.

ALBUMEN (ăl bū'mĕn): the white of an egg; a certain type of protein.

ALIMENTARY CANAL (ăl ĭ mĕn'tā rī): a collective term indicating all the organs through which the food passes through the body.

AMPHIBIAN (ăm fib'ī ăn): an animal, such as the frog, which can live in either the air or the water.

AMYLOPSIN (ăm ĭ lõp'sin): one of the ferments, or enzymes, in the pancreatic juice; it assists in the digestion of starch.

ANABOLISM (ăn ăb'ō līz'm): the process of building up new cells and tissues from food.

ANATOMY (ă năt'ō mī): the study of the structure of living things.

- ANGIOSPERM (ăn'jĩ ô spûrm): a plant which bears seeds in an ovary.
- ANNELIDA (ăn ê lĩd'â): a phylum of animals including earthworms, leeches, etc.
- ANTENNÆ (ăn tẽn'ê): appendages usually bearing sense organs, which appear on the head of certain animals.
- ANTERIOR (ăn tẽ'rĩ êr): that part of the body toward the head end of an animal.
- ANTHER (ăn'thêr): the top, pollen-bearing part of the stamen.
- ANTHERIDIA (ăn thêr id'ĩ â): the sperm-bearing organs of certain plants, such as the ferns and the mosses.
- ANTIBODIES (ăn'tĩ bõd êz): substances produced in the blood of an animal which neutralize the poisons given off by germs.
- ANTITOXIN (ăn tĩ tõk'sĩn): a substance which neutralizes the effect of poisons given off by germs; substances manufactured by an animal having a certain disease, and which can be injected into the body of another animal to assist in the neutralization of the poisons given off by germs.
- ANUS (ă'nũs): the posterior opening of the alimentary canal.
- AORTA (ă ôr'tâ): the large artery leading from the left ventricle through which the blood passes to all parts of the body excepting the lungs.
- ARACHNIDA (ă răk'nĩd â): a class of arthropods including spiders, scorpions, etc.
- ARCHEGONIA (ăr kê gõ'nĩ â): egg-bearing organs in certain plants.
- ARTERY (ăr'têr ĩ): a blood vessel which carries blood away from the heart.
- ARTHROPODA (ăr thrõp'õ dă): a group of animals including the insects, crayfish, spiders, etc.
- ASEXUAL REPRODUCTION (ă sêk'shũ đĩ): reproduction in which no germ cells or gametes are involved.
- AURICLE (ô'rĩ k'l): one of the chambers of the heart.
- AXON (ăk'sõn): that part of the neuron which carries impulses away from the cell body.
- BACILLUS (bă sĩl'ũs): a rod-shaped bacterium.
- BAST (bást): the part of the bark which is fibrous.
- BIENNIAL (bĩ ên'ĩ đĩ): a plant which lives for two summers.
- BINARY FISSION (bĩ'nâ rĩ fĩsh'ũn): the division of a cell into two daughter cells.
- BLASTULA (blăstũ lă): the stage in the development of an organism in which the cells are arranged in the shape of a hollow ball.
- BLATTIDÆ (blăt'ĩ dẽ): a family of insects, including the cockroaches.
- BREED TRUE: to produce offspring of the same unit characters as the strain or variety.
- BRONCHI (brõng'kĩ): the branches of the trachea which lead to the lungs.
- BRYOPHYTES (brĩ'õ fĩtz): a group of plants consisting of the mosses and the liverworts.
- CALORIE (kăł'õ rĩ): the amount of heat required to raise the temperature of one kilogram of water one degree centigrade; the small calorie is the amount of heat necessary to raise the temperature of one gram of water one degree centigrade.

- CALYX** (kā'lıks): the leaf-like, usually green, parts of a flower which surround the petals.
- CAMBIUM** (kām'bĩ ũm): the layer of active cells in the higher plants which divide and form new wood and bark.
- CAPILLARY** (kăp'ĩ lâ rĩ): a small blood vessel between the arteries and the veins.
- CARBOHYDRATES** (kăr bô hĩ'drätz): a class of foods containing carbon, hydrogen, and oxygen; sugar and starch are examples.
- CARNIVOROUS** (kăr nĩv'ô rŭs): animals which feed upon flesh.
- CARTILAGE** (kăr'tĩ lâj): an elastic tissue which composes the skeleton of most young, vertebrate animals.
- CATABOLISM** (kă tăb'ô lĩz'm): the process by which the complex body substances are broken down into simpler substances.
- CELLULOSE** (sě'ũ lōs): the material which composes the walls of plant cells.
- CEPHALOPODA** (sě á lô'pôđ á): a class of mollusks including squids, octupuses, etc.
- CEPHALOTHORAX** (sě á lô thō'răks): the part of the body, as in the crayfish, which results from a fusion of the head and thorax.
- CEREBELLUM** (sěr ě běl'ŭm): one of the divisions of the dorsal part of the brain; it has to do with coördinating movements.
- CEREBRAL CORTEX** (sěr'ě brăl kôr'těks): the outer layer of gray matter of the cerebrum.
- CEREBRUM** (sěr'ě brŭm): the anterior portion of the brain; the part of the brain which enables man to think.
- CHEMOTROPISM** (kê môt'rô pĩz'm): the response of an organism to a chemical stimulus.
- CHITIN** (kĩ'tĩn): the hard material in the outer covering of animals such as insects and crustaceans.
- CHLOROPHYLL** (klô'rô fil): the green coloring matter of plants.
- CHLOROPLAST** (klô'rô plăst): the grain containing the green coloring material in plants.
- CHORDATA** (kôr da'tá): an animal phylum including all animals with a notochord or a backbone.
- CHROMOSOME** (krô'mô sôm): one of the bodies in the nucleus which appears during cell division.
- CILIA** (sĩ'ĩ á): small projections which aid the cell in moving or in setting up currents in liquid.
- CLEAVAGE** (klěv'áj): the divisions of the egg cell which result in the blastula stage of development.
- COAGULATE** (kô ág'ũ lăt): to change a liquid into a curdled state; example, white of egg in alcohol.
- COCOON** (kô kôon'): the envelope in which the larvæ of certain animals pass through the pupa stage.
- CŒLENTERATA** (sê lěn těr ât'á): an animal phylum including jellyfish, coral, etc.
- COLEOPTERA** (kôl ě ôp'těr á): an insect order including beetles, etc.
- CONDITIONED REFLEX** (rě'flěks): an acquired response which is substituted for an inherited response.

CONJUGATION (kõn jõõ gā'shŭn): the fusion of two similar cells in reproduction.

CONTRACTILE VACUOLE (kõn trāk'tīl vāk'û ōl): a reservoir in a one-celled organism in which waste products are collected and expelled from the cell.

CORTEX (kôr'těks): the outer surface of an organ.

COTYLEDON (kõt ĭ lē'dŭn): the seed leaves in an embryo.

CRETINISM (krē'tīn ĭz'm): idiocy.

CRUSTACEA (krŭs tā'shē á): an animal class including snails, lobsters, barnacles, etc.

CUTIN (kŭ'tīn): a waxy substance in the epidermis of plants which helps prevent evaporation of water from the inner parts.

CYTOPLASM (sī'tō plāz'm): the liquid part of the protoplasm in a cell.

DAM (dām): female parent; especially applied to four-footed animals.

DENDRITE (dēn'drīt): that part of a nerve cell which conveys the impulse toward the cell body.

DERMIS (dŭr'mīs): the skin beneath the epidermis.

DIASTASE (dī'á stās): an enzyme in plants which changes starch to sugar.

DICOTYLEDON (dī kõt ĭ lē'dŭn): a plant whose seed contains two seed leaves or cotyledons.

DINOSAUR (dī'nō sŏr): an extinct animal related to the modern reptile.

DIPTERA (dĭp'tēr á): an order of insects including the housefly.

DORSAL (dŏr'sāl): the back part of the body of an organism.

DUCTLESS GLAND (dŭkt'lēs glānd): an organ which manufactures hormones and pours them directly into the blood.

ECHINODERMATA (ē kĭ nŏ dŭrm ā'tā): an animal phylum including starfishes, sea urchins, etc.

EFFECTOR (ě fěk'tēr): a nerve cell which conducts a nerve impulse to a gland or muscle.

EMBRYO (ěm'brĭ ō): the early stage of development of an organism.

EMBRYOLOGY (ěm brĭ ōl'ō jĭ): a study of the early development of an organism.

ENDOSPERM (ěn'dŏ spŭrm): a tissue containing food material, formed within the embryo sac in seed plants.

ENDOCRINE GLAND (ěn'dŏ krĭn): an organ which manufactures hormones and pours them directly into the blood.

ENZYME (ěn'zīm): a substance secreted by a gland, which has the power to cause chemical changes to take place, as fermentation, without itself being used up in the process.

EPIDERMIS (ěp ĭ dŭr'mīs): the outer layer of the skin; the outer layer of cells in plants.

EQUISETUM ARVENSE (ěk wĭ sē'tŭm ár vĕn'sě): a kind of horsetail plant.

EROSION (ě rŏ'zhŭn): the wearing down of the earth by water, air, and plants.

ESOPHAGUS (ě sŏf'á gŭs): the tube which conveys the food from the mouth to the stomach.

EXO-SKELETON (ěk'sŏ-skĕl'ē tŭn): a non-living, hard material forming the outer surface of the body and used for protection, as in the crayfish.

EXPIRATION (ěk spī rā'shǎn): the passage of the air from the lungs to the outer air.

FACET (fās'ět): the surface of one of the small eyes in a compound eye.

FATS: compounds of carbon, hydrogen, and oxygen; a class of food materials used mainly for energy and storage, as, for example, butter.

FAUNA (fô'nà): the animal population of a given region.

FERMENT (fēr mēnt'): an enzyme; the changing of sugar to alcohol and carbon dioxide by yeast.

FIBROVASCULAR BUNDLES (fī brô vās'kû lâr): bundles of long cells running lengthwise of the stem of the plant and providing passageway for liquids and strengthening to the stem.

FILTRATE (fil'trât): the liquid which has passed through a filter paper.

FISSION (fish'ŭn): the splitting of a cell into two parts.

FLORA (flô'rà): the native plants of a given region.

FOLLICLE (fôl'ĩ k'l): the cavity in which a hair is produced.

FROND (frönd): the leaf of a fern.

FRUIT: the ripened ovary and its contents, together with any structures which adhere to the ovary wall.

FUNGUS (fŭng'gŭs): molds, mildews, rusts, smuts, and mushrooms. Plants lacking chlorophyll.

GALL (gôl): a swelling on plants caused by certain parasites, usually the larvæ of insects.

GAMETE (gām'ēt): a cell which unites with another cell to form a zygospore.

GAMETOPHYTE (gá mē'tô fit): the generation of a plant which bears the eggs and sperms.

GANGLION (gǎng'glĩ ōn): a group of nerve cells.

GASTRULATION (gás tröö lā'shǎn): the process in the development of the embryo which results in a two-layered sac enclosing a central cavity.

GENE (jĕn): a factor in the chromosome which conditions a character of an organism.

GENUS (jē'nŭs): a division of the system of classification; a main division of a family; a group of closely related species.

GEOTROPISM (jē ô't rô pĭz'm): the tendency of growing organs to assume a definite position with relation to the pull of gravity, as, for example, the growth of plant roots downward.

GERMINATION (jŭr mĩ nā'shǎn): the starting of growth in a pollen grain or seed.

GLAND (glând): a group of cells which secrete or excrete some certain substance.

GLYCOGEN (glĩ'kô jĕn): a carbohydrate which is stored in the liver.

GYMNOSPERMS (jĩm'nô spŭrms): plants bearing naked ovules and seeds, as, for example, pine, spruce, and cedar.

HABITAT (hăb'ĩ tăt): the immediate surroundings or environment of an organism.

HAUSTORIA (hôs tō'rĩ á): a root-like part of a parasitic plant which enters the stem or root of another plant, and thereby obtains nourishment.

HEMIPTERA (hê mǎp'têr á): an insect order including bugs and lice.

HERBIVOROUS (hêr bǐv'ô rŕs): animals which feed upon plants.

HEREDITY (hê rêd'ĩ tĩ): transmission of characteristics from generation to generation.

HILUM (hĩ'lǎm): the scar on a seed showing the place of attachment to the fruit.

HOMOLOGY (hồ mỗl'ô jĩ): structural resemblance due to a descent from a common form, regardless of function.

HORMONE (hồ'r mōn): a substance manufactured usually by ductless glands, which assists the regulation of body activities.

HOST: the organism upon which a parasite lives and usually obtains nourishment.

HUMUS (hũ'mŭs): decayed or decaying organic material in the soil.

HYBRID (hĩ'brĩd): the offspring of parents which differ in regard to some heritable characters; usually the offspring of two different species.

HYDROPHYTE (hĩ'drô fit): a plant living in water or in a very wet habitat.

HYDROTROPISM (hĩ drôt'rô pĩz'm): the tendency of organisms to respond to the presence of water.

HYMENOPTERA (hĩ mễn ôp'têr á): an insect order including ants, bees, wasps, etc.

HYPHÆ (hĩ'fê): the upright thread-like parts of a fungus.

HYPOCOTYL (hĩ pồ kôt'ĩl): the part of the embryo below the cotyledons.

ICHNEUMON FLY (ĩk nũ'mỗn): an insect of the order Hymenoptera, whose larvæ are parasites on other larvæ.

IMAGO (ĩ mǎ'gô): the adult stage of an insect with a metamorphoses.

IMBIBITION (ĩm bĩ bĩsh'ŭn): the action of organic substances in absorbing water.

IMMUNE BODIES: materials produced in the body of an animal suffering from a disease which neutralize the poisons produced by the germ causing the disease.

IMMUNITY (ĩ mũ'nĩ tĩ): freedom from susceptibility to a certain disease.

INOCULATE (ĩn ôk'ũ lăt): to infect or to cause a disease in an organism.

INORGANIC MATTER: material composed of other than plant or animal material.

INTERNODE (ĩn'têr nōd): the distance between two nodes.

INVERTEBRATE (ĩn vũr'tê brăt): without a backbone.

IRRITABILITY (ĩr ĩ tǎ bĩ'ĩ tĩ): the ability to respond to a stimulus.

LACTEAL (lǎk'tê ǎl): a small tube carrying to the lymph vessels fats absorbed in the intestines.

LARYNX (lǎr'ĩngks): the upper part of the windpipe.

LEGUMES (lêg'ũm; lê gũm'): an order of plants, as, for example, beans, peas, clover, alfalfa.

LENTICEL (lên'tĩ sêl): a breathing pore in a plant stem.

LEPIDOPTERA (lêp ĩ dôp'têr á): an insect order including moths and butterflies.

LEUCOCYTE (lũ'kô sīt): a white blood corpuscle.

LIFE CYCLE: stages in the development of an organism from fertilized egg to adult.

- LIGAMENT (līg'á měnt): the connective tissue which binds the bones together.
- LIPASE (líp'ās): an enzyme which digests fat; steapsin.
- LOAM (lōm): soil containing clay, sand, and decayed organic materials.
- LYMPH (līm̃f): the liquid part of the blood and the white blood corpuscles which have passed through the walls of the capillaries into the spaces between the cells.
- LYMPHATICS (līm fāt'iks): vessels containing lymph.
- MAGGOT (măg'ŏt): a larva of an insect such as the housefly.
- MALPHIGIAN TUBES (măl pig'ī ăn): tubes in insects which empty nitrogenous wastes into the alimentary canal; excretory organs.
- MAMMAL (măm'ăl): an animal belonging to the vertebrate class mammalia; an animal which nourishes its young with milk from mammary glands.
- MANDIBLE (măn'dī b'l): the third pair of appendages of a crayfish; a jaw.
- MARSUPIAL (măr sū'pī ăl): a mammal which carries its young in a pouch.
- MAXILLA (măk sīl'á): a mouthpart of insects and of crustaceans; a head appendage.
- MAXILLIPED (măk sīl'ī pēd): one of the last three appendages of the head of the crayfish and its allies.
- MEDULLA OBLONGATA (mē dŭl'á ōb lŏng gā'tá): the posterior portion of the brain of vertebrate animals.
- MEDULLARY RAYS (mēd'ŭ lă rī; mē dŭl'á rī): horizontal vessels in the stems of plants which connect the inner and outer portions.
- MELANOPLUS (mēl ăn ōp'lŭs): a genus of locusts.
- MESOPHYLL (mēs'ō fil): the thin-walled cells which make up the interior of a leaf.
- MESOPHYTE (mēs'ō fīt): a plant adapted to an environment having moderate amounts of moisture in the soil and air.
- METABOLISM (mē tăb'ō līz'm): the chemical processes in an organism involving the building up and tearing down of the living tissues.
- METAMORPHOSIS (mēt á mŏr'fŏ sīs): the changes which take place during the development of a larva into an adult.
- MICROBES (mī'krŏbz): bacteria.
- MICROPYLE (mī'krŏ pīl): a small opening in a seed at the point where the pollen tube entered the ovule.
- MIMICRY (mīm'ik rī): a resemblance of an organism to another organism, presumably an adaptation for protective purposes.
- MOLLUSCA (mŏl ŭsk'á): an animal phylum including snails, clams, etc.
- MONGREL (mŭng'grēl): an animal of mixed breeding; an animal of no well-defined breed.
- MONOCOTYLEDON (mŏn ō kŏt ī lē'dŭn): a plant with one cotyledon or seed leaf.
- MOTOR AREAS: a part of the brain from which nerve impulses are sent to the muscles.
- MUTANT (mŭ'tănt): an organism which exhibits one or more characters unlike the characteristics of the species.
- MYCELIUM (mī sē'li ŭm): the threadlike mass of hyphæ present in certain fungi.
- MYRIAPODA (mīr ī á'pŏd á): a class of arthropoda including centipedes.

**NEMATHELMINTHES** (nēm ă thēl'mĩnth ēz): an animal phylum including thread worms.

**NERVE**: a group of parallel nerve fibers bound together in a cable.

**NEURON** (nū'rŏn): a nerve cell with its processes (axons and dendrites).

**NODE** (nŏd): the point at which a leaf grows from a stem; the places on stems where branches arise.

**NOTOCHORD** (nŏ'tŏ kŏrd): an elastic, rod-shaped structure found on the dorsal side of all chordates.

**NYMPH** (nĩmf): a young insect that resembles the adult in most of its characteristics.

**OLFACTORY LOBE** (ŏl făk'tŏ rĩ lŏb): a region of the brain concerned with the sense of smell.

**OMASUM** (ŏ mă'sũm): the third division of the stomach of a ruminant (cud-chewing) animal, as, for example, sheep.

**OMNIVOROUS** (ŏm nĩv'ŏ rĩs): the term applied to an organism which feeds upon both plant and animal foods.

**OPTIC LOBE** (ŏp'tĩk): a region of the brain concerned with vision.

**OPTIMUM TEMPERATURE** (ŏp'tĩ mũm): the temperature at which an organism grows best.

**ORGAN**: a group of tissues performing a special function.

**ORGANIC MATTER** (ŏr găn'ĩk): substances that occur in living things or as a result of chemical processes going on in living organisms.

**ORGANISM** (ŏr'găn ĭz'm): a living being, plant or animal.

**ORTHOPTERA** (ŏr thŏp'tēr ă): an insect order including grasshoppers, crickets, and cockroaches.

**OSMOSIS** (ŏs mŏ'sĩs): the diffusion or passage of two solutions of unequal concentrations through a semi-permeable membrane.

**OSMOTIC PRESSURE** (ŏs mŏt'ĩk): the force generated by the contact of two solutions of unequal concentration separated by a semi-permeable membrane.

**OVARY** (ŏ'vă rĩ): the organ in which the immature female germ cells are lodged.

**OVI PAROUS** (ŏ vĩp'ă rĩs): egg-laying.

**OVIPOSITOR** (ŏ vĩ pŏz'ĩ tēr): special organs which certain animals possess for depositing eggs, as, for example, in the grasshopper.

**OVULE** (ŏ'vũl): small bodies in the pistil which become the seed after fertilization.

**OXIDATION** (ŏk sĩ dă'shĩn): the combination of a substance with oxygen.

**PALEONTOLOGIST** (pă lē ŏn tŏl'ŏ jĩst): one who studies the fossil record of life.

**PALISADE CELLS**: long, columnar cells of a leaf usually situated below the upper epidermis.

**PANCREAS** (păng'krē ăs): a gland which secretes and discharges into the intestines a fluid containing several digestive enzymes.

**PARENCHYMA** (pă rēng'kĩ mă): large, thin-walled cells found in the center of most plant stems.

**PASSIVE IMMUNITY**: freedom from susceptibility to a disease in which the body plays no part in the production of the immune bodies.

- PASTEURIZATION (pàs tēr ĭ zā'shǎn): heating of milk to 60 degrees centigrade for 30 minutes to prevent the growth of bacteria.
- PATHOGENIC GERM (pǎth ô jěn'ík): one that causes a disease.
- PEDIGREE (pěd'ĩ grē): the ancestry of an organism.
- PEPSIN (pěp'sin): an enzyme of the gastric juice which acts upon proteins and changes them into substances which can be absorbed.
- PERIOD OF GESTATION (jěs tā'shǎn): the time which a mammal spends in the body of its mother.
- PERIOD OF INCUBATION (ĩn kũ bā'shǎn): the time which an organism spends while developing within the confines of an egg.
- PERMEATE (pũr'mě āt): to diffuse through a substance or space, especially through minute pores in a substance or membrane.
- PETAL: any single leaf in the corolla, or colored portion, of a flower.
- PETIOLE (pět'ĩ ōl): a slender stem, or leaf stalk, which fastens the leaf to the larger stem of a plant.
- PHARYNX (fār'ingks): the very top part of the digestive tube which connects the mouth to the esophagus; in lower animals it is the part into which the gill slits open.
- PHLOEM (flō'ēm): the outer portion of the plant fibrovascular bundle containing the sieve tubes for conducting food.
- PHOTOSYNTHESIS (fō tō sǐn'thē sīs): the process by which the green plant leaf forms starch from water and carbon dioxide with the aid of sunlight and chlorophyll.
- PHOTOTROPIC (fō tō trōp'ík): responsiveness to stimulation by light.
- PHYLUM (fĩ'lǔm): the very largest groups into which plants or animals are divided in classifying them.
- PISTIL (pĩs'til): that part of a seed-bearing plant which contains the seeds.
- PITH: the loose, spongy, connective tissue in the centre of the stem of dicotyledonous plants.
- PITUITARY BODY (pĩ tũ'ĩ tâ rĩ): a ductless gland situated on the ventral side of the middle portion of the brain.
- PLACENTA (plá sěn'tá): in animals, a vascular structure attaching the young embryo to the wall of the uterus so that food and oxygen can be absorbed from the blood of the mother; in plants, the portion of the ovary wall to which the seeds are attached.
- PLACENTAL MAMMAL: any mammal in which the young are attached to the wall of the uterus by a placenta. Almost all mammals are placental.
- PLASMA MEMBRANE (plāz'má): the very thin, almost impermeable membrane formed on the surface of all living cells.
- PLATYHELMINTHES (plăt ĭ hěł'mínth ēz): an animal phylum including flatworms.
- PLEUROCOCCLUS (plōō rô kōk'ūs): a minute, single-celled genus of green algae. Usually found in stagnant water, on the bark of trees, etc.
- PLUMULE (plōō'mūl): the primary bud at the very tip of the germinating seed plant; found at the tip of the stem in monocotyledons, and between the seed leaves in dicotyledons.
- POLLEN (pōl'ēn): the male spores of seed-bearing plants; it is usually in the form of a fine yellow powder.

POLLINATION (põl ĭ nā'shñn): the process of transferring the pollen grains from the stamen to the pistil.

POLYTRICHUM JUNIPERINUM (põ līt'řĩ kũm jōō nĩ pēr'ĩ nũm): hair-cap moss.

PORIFERA (põ rĩf'ēr à): an animal phylum including the sponges.

POSTULATE (põs'tũ lāt): any rule or law which fits all the known facts but which is not completely proven.

PREHENSION (prē hēn'shñn): the act of grasping with the hand or other extremity.

PROBOSCIS (prō bõs'is): any sort of a tubular prolongation of the head or mouth region of an animal; usually movable.

PROGENY (prõj'ē nĩ): the collective name for all the offspring of any particular plant or animal.

PROPERTIES: the specific characteristics of an organism or substance.

PROTECTIVE COLORATION: the development of a color scheme by an animal of such a nature that it harmonizes perfectly with the surrounding landscape.

PROTEIN (prõ'tē ĭn): one of the three main classes of foods; it differs from other kinds of food in that it contains nitrogen.

PROTONEMA (prõ tō nē'mā): the algæ-like base filament of mosses; it is formed by the germination of asexual spores and bears the sexual plants.

PROTOPLASM (prõ'tõ plāz'm): a very complex mixture of proteins forming the essential material of all plant and animal cells; the basis of all life.

PROTOZOA (prō tō zō'ā): the phylum of animals into which all the single-celled animals are grouped.

PTERIDOPHYTES (tēr'ĩ dō fĩt): the phylum of plants which includes the higher, non-seed-bearing plants; commonly called ferns.

PTYALIN (tĩ'ā lĩn): an enzyme, or digestive ferment, found in the saliva of man and many animals; it acts to split the starches into sugars.

PULMONARY ARTERY (pũl'mō nā řĩ): the large artery carrying impure blood from the heart to the lungs.

PULMONARY VEIN: the large vein that collects the purified blood in the lungs and returns it to the heart.

PUPA (pũ'pā): the quiescent form which insects assume to go through the metamorphosis from larva to adult.

PURE-BRED: an animal or plant whose ancestors are known to have all belonged to one breed, and which will, itself, breed true to type.

PURE CULTURE: a culture containing organisms of one species only; usually refers to bacteria, though it may be applied to any plants or animals.

PYRUS (pĩ řũs): a genus of plants including apples, pears, and quinces.

QUARTZ (kwôrts): a special form of sand that is transparent and usually colorless.

RADICLE (rād'ĩ k'l): the undeveloped root of a seed or young embryo.

RANA CATESBIANA (rā'nā kāt ēs bĩ ā'nā): bullfrog. PIPPIENS (pĩ'pĩ ěns): leopard frog.

RECEPTACLE (rē sēp'tāk'l): the base to which the sporangia of mosses and ferns are attached; the base upon which the flowers are borne.

- RECEPTOR (rê sêp'tôr): any specialized nerve cell for receiving stimuli.
- REFLEX (rê'flêks): automatic subconscious response to a specific stimulus.
- REFLEX ARC: all the nerves involved in conveying both the stimulus and response impulses necessary to produce a particular reflex action.
- REGENERATION (rê jên êr ā'shŭn): the replacing of lost parts by lower plants and animals.
- REJUVENATION (rê jōō vê nā'shŭn): to re-strengthen or to make as if young again.
- RESPIRATION (rês pī rā'shŭn): the process of breathing by cells in which oxygen is used to secure energy from foods and a waste gas is thrown off.
- RETICULUM (rê tîk'û lŭm): the second stomach of ruminant (cud-chewing) animals, as the cow.
- RETINA (rêt'î nâ): the inner coat of the eye which is sensitive to light and on which the image falls.
- RHIZOIDS (rî'zoidz): root-like hairs of mosses and ferns.
- RHIZOME (rî'zôm): an underground stem.
- ROSETTE (rô zêt'): leaves of a plant, such as the dandelion or plantain, that are arranged in the form of a rose and lie close to the ground.
- RUMEN (rōō'mên): the first stomach of a cow or other ruminant.
- SAPROPHYTE (săp'rô fit): a plant that does not make its own food, but lives on dead organisms.
- SCAPULA (skăp'û lâ): the shoulder blade.
- SCION (sî'ŭn): a bud, shoot, or other part of a plant that is taken from one plant and grafted on to another.
- SECRETION (sê krê'shŭn): a substance prepared by the glandular tissues in the body; for example, saliva is secreted by the salivary glands.
- SEDIMENTARY (sêd ĭ mên'tâ rĭ): formed by sediment or fine particles of material in water that settle to the bottom; limestone and sandstone are sedimentary rocks.
- SEED COAT: the membrane that covers a seed.
- SEEDLING: a young plant grown from seed.
- SEGMENTATION (sêg mên tă'shŭn): separation into parts.
- SENSATION: awareness of light, sound, heat, etc., resulting from nervous impulses carried to the brain.
- SENSE ORGAN: an organ, such as the eye, that responds to stimulation of a special kind.
- SEPAL (sê'păl): a leaf or division of the calyx.
- SERUM (sê'rŭm): the pale, yellowish, watery substance which separates from the clot during the coagulation of the blood.
- SETA (sê'tâ): the stem that supports the spore case in moss plants; any bristle-like organ of lower animals.
- SHOOT: the stem and leaves of a plant taken together, especially one that has newly developed.
- SIEVE TUBE (sĭv): the elongated cells in the bark of plants that conduct most of the manufactured food.
- SILT: fine earth that deposits from water.
- SIMPLE EYE: a small eye composed of a single lens, such as occur in the grasshopper or locust.

- SINUS** (sī'nŭs): a cavity in the bones of the head that connects with the nose.
- SIRE** (sīr): the male parent, particularly among four-footed animals.
- SOLVENT** (sōl'vent): a substance which dissolves other substances, as water is a solvent of sugar, salt, etc.
- SOMITE** (sō'mīt): one of the sections into which the bodies of many animals are divided; the somites in the abdomen of most insects are easily distinguishable.
- SPAWN** (spôn): the laying of eggs by fish, oysters, etc.
- SPERM** (spûrm): the male reproductive cells of plants or animals.
- SPERMATOPHYTE** (spûr'mă tō fit): a seed-bearing plant.
- SPIRACLE** (spīr'ă k'l): a breathing pore in lower animals.
- SPLEEN** (splēn): a large, purplish, ductless gland located at the left end of the stomach.
- SPORANGIUM** (spō răn'jī ŭm): a spore case in which asexual spores are produced.
- SPORE** (spōr): a cell which can produce a new individual without fertilization.
- SPRAIN**: the wrenching or tearing of ligaments in a joint.
- STAMEN** (stā'měn): the floral organ that bears pollen.
- STERILE** (stēr'il): lack of reproductive organs or the power to produce young.
- STIGMA** (stīg'mă): the upper part of the pistil of a flower.
- STIMULANT** (stīm'ŭ lănt): any substance that can cause the nervous system to become more active.
- STIMULUS** (stīm'ŭ lŭs): any condition which brings about a response in an organism.
- STOLON** (stō'lŏn): a shoot from a parent plant growing underground as a runner or above ground producing buds and a new plant.
- STOMA, plural STOMATA** (stō'mă, stō'mă tă): an opening in the epidermis of a plant protected by guard cells, through which gas exchange takes place with the surrounding atmosphere and the intercellular spaces.
- STRAIN**: groups of plants or animals that differ slightly from the race to which they belong.
- STRATA** (stră'tă): bodies of rock or earth formed by natural causes, and consisting usually of a series of layers lying between layers of other kinds of rock or earth.
- STYLE**: the part of the pistil between the stigma and the ovary, or the stem-like part of the pistil.
- SUGAR**: a carbohydrate food composed of carbon, hydrogen, and oxygen, soluble in water and sweet tasting.
- SWARMING**: the division of a colony of bees or other insects into two groups, one half leaving to seek a new home; it occurs only when a new queen is born.
- SWIMMERETS** (swīm'ēr ěts): the swimming appendages on the abdomen of a crayfish.
- SYMBIOSIS** (sīm'bī ō sīs): organisms of different nature living in a state of mutual helpfulness.
- SYMMETRY** (sīm'ĕ trī): a balanced arrangement of parts.

- TADPOLE:** a frog or toad in the larval stage of its development.
- TALON** (tǎl'ŭn): the curved claw of a bird of prey.
- TANKAGE** (tǎngk'āj): dried animal food prepared from slaughterhouse waste materials.
- TENDRIL** (tĕn'drĭl): a slender, leafless twining organ of such plants as grapevines that affords a means of attachment for support.
- TENTACLE** (tĕn'tá k'l): a flexible appendage of many lower animals used as a feeler, or as an organ of motion or attachment.
- THALLOPHYTES** (thǎl'ô fitz): the lowest group of plants; commonly composed of threadlike filaments.
- THERMOTROPISM** (thĕr môt'rô pĭz'm): response of plants and animals to temperature.
- THIGMOTROPISM** (thĭg môt'rô pĭz'm): tendency of plants and animals to react to the stimulus of touch.
- THORACIC DUCT** (thô răs'ĭk): the main canal of the lymphatic system.
- THORAX** (thô'rǎks): in insects the part of the body between the head and abdomen; the chest cavity in man and higher animals.
- THYROID GLAND** (thĭ'roid): a large ductless gland in the lower front part of the neck; the enlargement of this gland is called a goiter.
- TOXIN** (tôk'sĭn): a poisonous protein substance formed by parasites.
- TRACHEA** (trā'kê â): the main passage of the respiratory system, which conducts air to and from the lungs; commonly known as a "wind-pipe."
- TRACHEAL TUBE** (trā'kê ăl): any of the branches of the trachea; commonly used in describing the respiratory system of animals.
- TRACHEID** (trā'kê ĭd): a thick-walled, elongated, woody cell pointed at both ends.
- TRANSPIRATION** (trǎn spĭ rǎ'shŭn): the giving off of water vapor from the green parts of plants.
- TROPISM** (trô'pĭz'm): the response of an organism to a particular stimulus, such as is shown by simple animals and plants.
- TRYPSIN** (trĭp'sĭn): an enzyme, or digestive ferment, found in the secretions of the pancreas; its function is to split protein matter.
- TUBER** (tŭ'bĕr): a small, fleshy, underground stem or shoot, having tiny leafy scales with buds or "eyes," as in the potato.
- TUBERCLE** (tŭ'bĕr k'l): a small, round, knoblike protrusion on an organism, such as the nodules on the roots of beans and peas, adventitious buds, or any small tuber.
- TUBERCULIN** (tŭ bŭr'kŭ lĭn): a liquid containing the growth products of the bacterium which causes tuberculosis.
- TURGIDITY** (tŭr jĭd'ĭ tĭ): the extent of swelling of a whole plant or animal, or one of its parts.
- TURGOR** (tŭr'gôr): a condition of normal rigidity, or stiffness, of living plant cells, caused by the pressure of water upon the cell walls.
- UNIT CHARACTER:** characteristics or traits of an individual which may be independently inherited.
- UREA** (ŭ'rê â): the main waste product of protein matter in the bodies of animals, as a result of the process of catabolism.

- VACCINATE** (vǎk'sǐ nāt): to inoculate mildly with the germ which causes a particular disease in order to immunize the organism to that disease in the future.
- VACCINE** (vǎk'sín): any disease-producing organism which is used for preventive vaccination.
- VACUOLE** (vǎk'û ôl): a little space in the cell of an organism, containing air or fluid secretions.
- VARIATION** (vǎ rǐ ā'shŭn): minor differences, not inheritable, which constantly show up in animals or plants, all of whom belong to the same breed or species.
- VASCULAR BUNDLES** (vǎs'kû lār): a bundle of conductive tissues found in the roots, stems, and leaf veins of the higher plants.
- VEIN**: any blood vessel carrying blood from the organ or tissue back toward the heart.
- VENA CAVA** (vē'ná kā'vá): the main vein, in higher vertebrates, carrying blood from the posterior half of the body to the heart.
- VENTRAL** (vēn'trāl): the lower, or abdominal, side.
- VENTRICLE** (vēn'trí k'l): a main pumping chamber of the heart; there is one right and one left ventricle in the higher vertebrates.
- VERMIFORM APPENDIX** (vûr'mǐ fôrm): a hollow, narrow tube, ending blindly, at the junction of the large and the small intestine.
- VERTEBRA** (vûr'tê brá): one of the bony segments which are jointed together to make up the vertebral column.
- VERTEBRAL COLUMN** (vûr'tê brǎl): the jointed, bony column surrounding the spinal cord; commonly the backbone.
- VERTEBRATES** (vûr'tê brǎtz): a phylum of animals characterized by having a vertebral column or backbone.
- VILLI** (vǐl'î): small wavy structures extending into the small intestine which increase the absorbing area of the intestine.
- VI'RUS** (vǐ'rŭs): the poison from any infectious disease.
- VITAMIN** (vǐ'tá mǐn): any of a group of food constituents, the chemical composition of which is not exactly known, and of which small amounts are necessary for the normal nutrition of animals, and possibly of plants.
- VIVIPAROUS** (vǐ vǐp'á rŭs): bringing forth young alive rather than by the laying of eggs.
- XEROPHYTES** (zē'rô fĭtz): plants that grow in dry situations, as desert plants.
- XYLEM** (zǐ'lēm): the woody portions of plants.
- ZYGOTE** (zǐ'gōt): a spore formed by the union of two gametes.

# INDEX

In using this index bear in mind the following facts: (a) all numbers refer to pages; (b) an italic number (54) indicates that there is an experiment on that page; (c) a number followed by an asterisk (167\*) indicates the presence of an illustration; (d) the index does not, as a rule, cover references to entire problems or units. For such references turn to the table of contents.

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